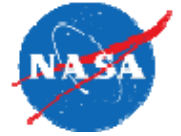




Evaluation of Vision System Technologies in Next Generation Air Transport System (NextGen) Operations

Stephanie Harrison

Acronym List



Acronym List	
AFFTC	Air Force Flight Technical Center
AGL	Above Ground Level
CMF	Cockpit Motion Facility
CVS	Combined Vision System
DF	Degrees of Freedom
DH	Decision Height
EFVS	Enhanced Flight Vision System
EVS	Enhanced Vision System
FAR	Federal Acquisition Regulation
FLIR	Forward Looking InfraRed
HUD	Head-Up Display

Acronym List	
MMWR	Millimeter Wave Radar
MS	Mean Square
NextGen	Next Generation Air Transport System
PF	Pilot Flying
PM	Pilot Monitoring
RFD	Research Flight Deck
RVR	Runway Visual Range
SS	Sum of Squares
StDev	Standard Deviation
SVS	Synthetic Vision Systems
TDZ/CL	Touchdown Zone/Centerline



Background: What are Vision System Technologies?

- Vision System Technologies are intended to create, supplement, or enhance the natural vision of pilots.
 - Enhanced Flight Vision Systems (EFVS)
 - Synthetic Vision Systems (SVS)
 - Combined Vision Systems (CVS)
- Forward Looking InfraRed (FLIR) EFVS
 - Only EVS approved for operational credit
 - Works in visibilities as low as 1000 ft RVR
- Proposed Rulemaking FAR 91-176
 - Allow for EFVS use in the visual segment all the way to touchdown
 - Initial implementations with FLIR EFVS invisibilities as low as 1000 ft RVR
- FLIR
 - Strengths: Night, Smoke, Haze
 - Weaknesses: Cannot penetrate all weather conditions
- How can Combined Vision Systems be used to provide for Equivalent Visual Operations during any lighting and atmospheric conditions?

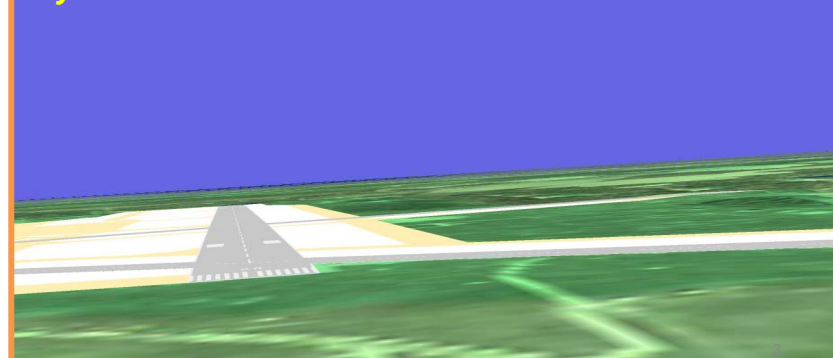
Out the Window View – 'Mark One' Eyeball



Enhanced Vision – Infrared Imaging Camera



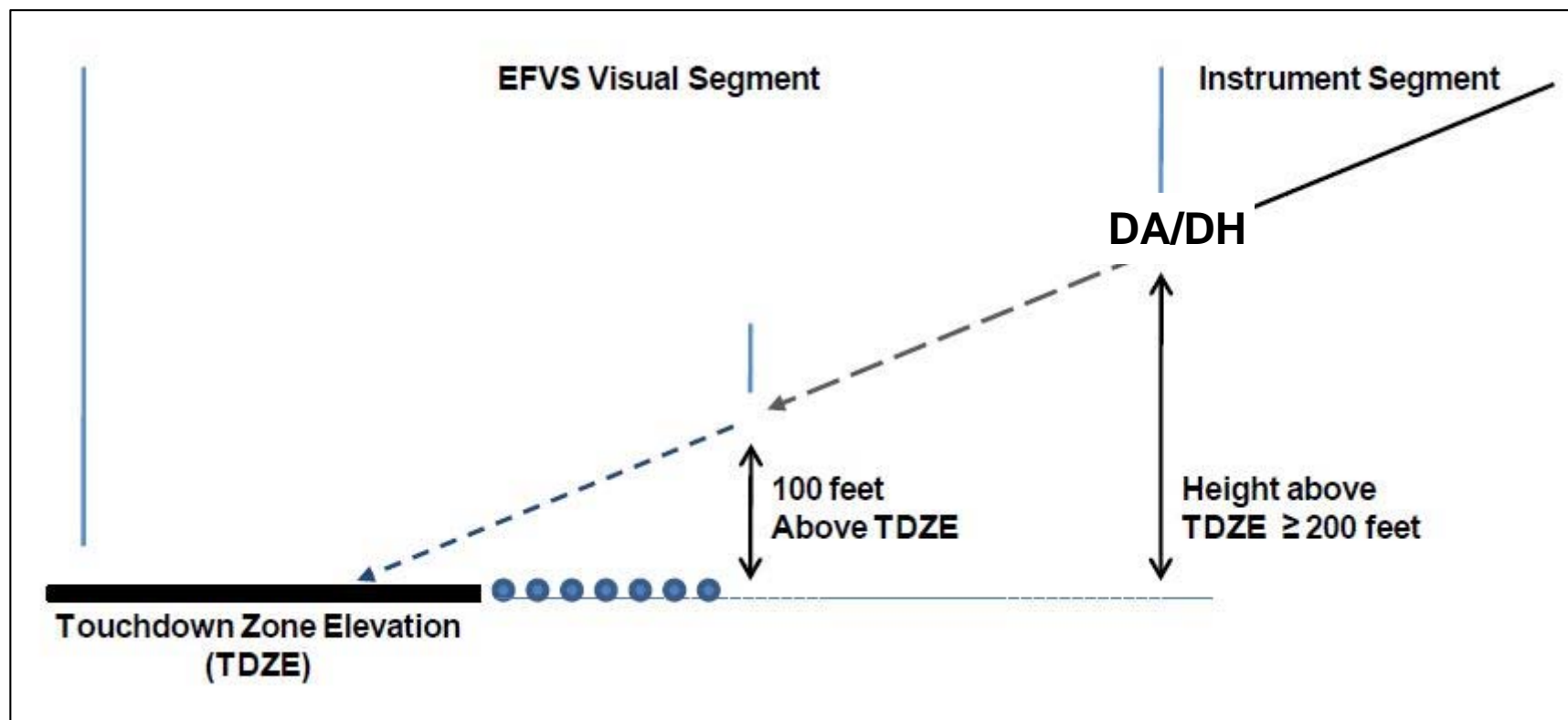
Synthetic Vision – Database & Nav. Solution





EFVS Operational Concept to be Tested

- Operational Concept: To enable straight-in instrument approach procedures (other than Category II and III) with published vertical guidance to touchdown, landing, and roll-out, to a safe taxi speed in visibility as low as 300 ft RVR by use of an approved EFVS without reliance on natural vision.





Design & Methodology: The 300 RVR Experiment

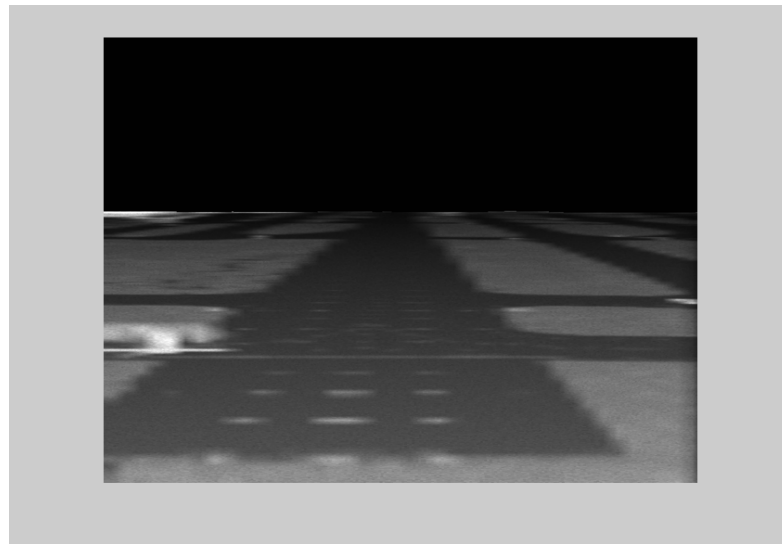
- Objective: Assess the use of vision system technologies on a Head-Up Display (HUD) for landing, touchdown, and rollout to a safe taxi speed in visibility as low as 300 feet runway visual range (RVR)
- 24 Airline Transport Pilots with HUD and EVS experience participated in a motion-based flight simulation experiment.



- Research was conducted in the Cockpit Motion Facility (CMF) in Research Flight Deck (RFD) simulator.
- Imagery :
 - Forward Looking InfraRed (FLIR)
 - Millimeter Wave Radar (MMWR)
 - Synthetic Vision Systems (SVS)
- Testing of various combinations of combined vision systems

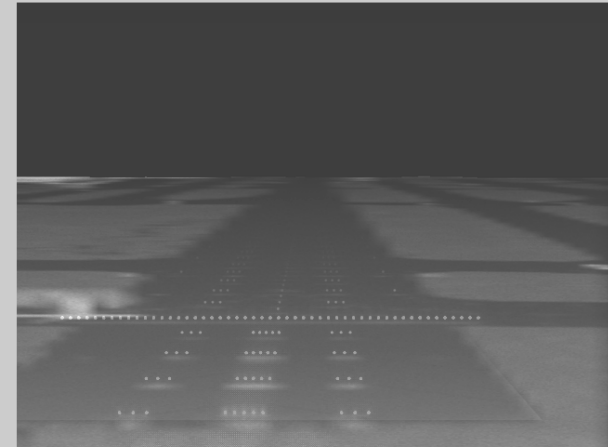


CVS Concept 1: Blending MMWR/FLIR with Contrast Enhancement



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Pixel-Averaged: Loss of Contrast



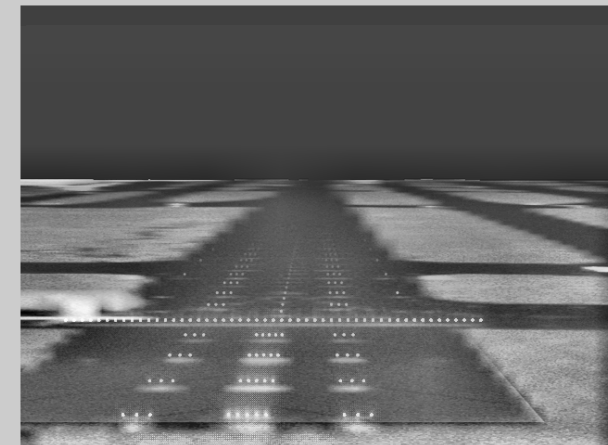
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Contrast Enhancement



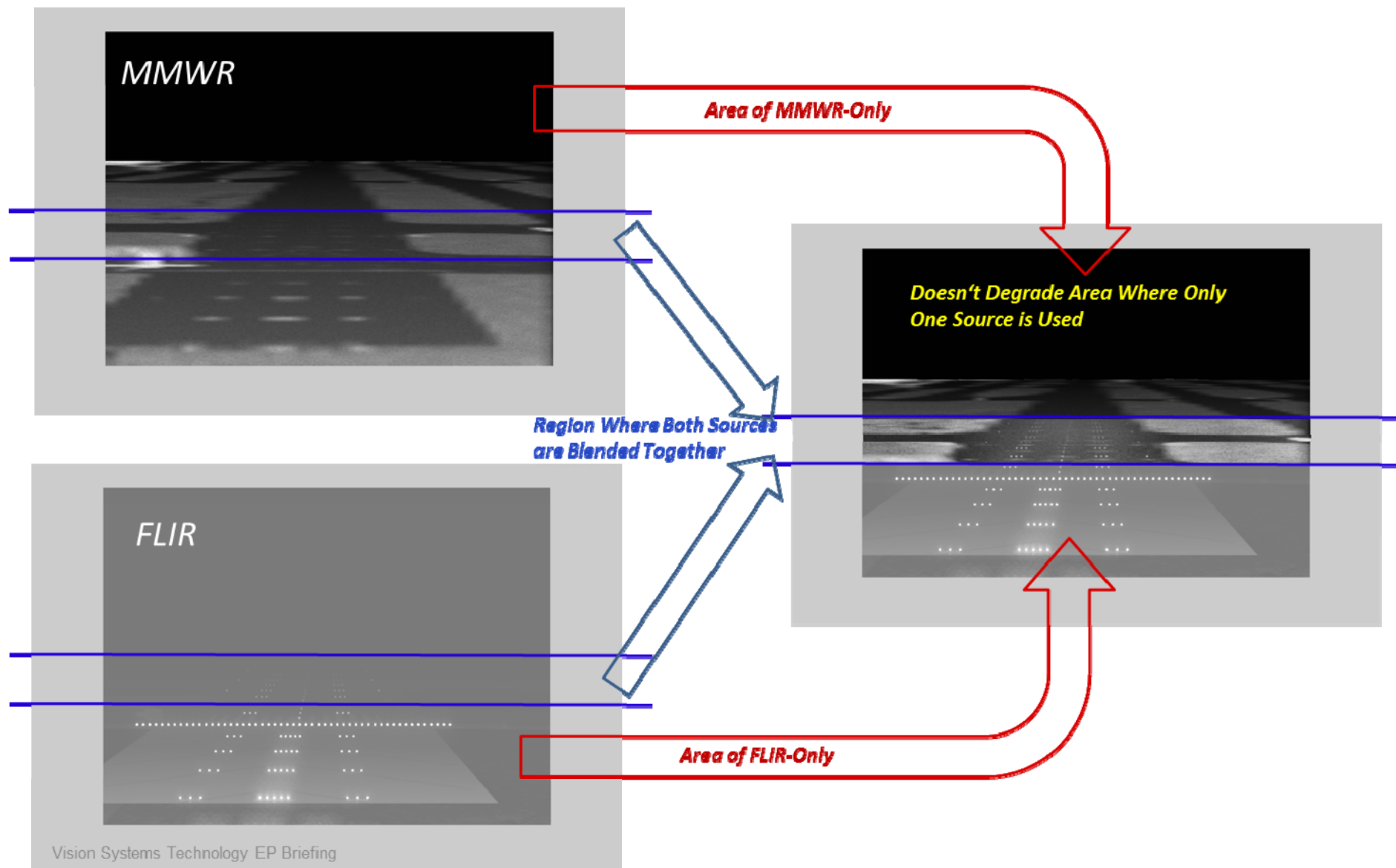
contrast



Blending Method Shows Equivalent Performance To Other Methods; Without Significant Computational Burden

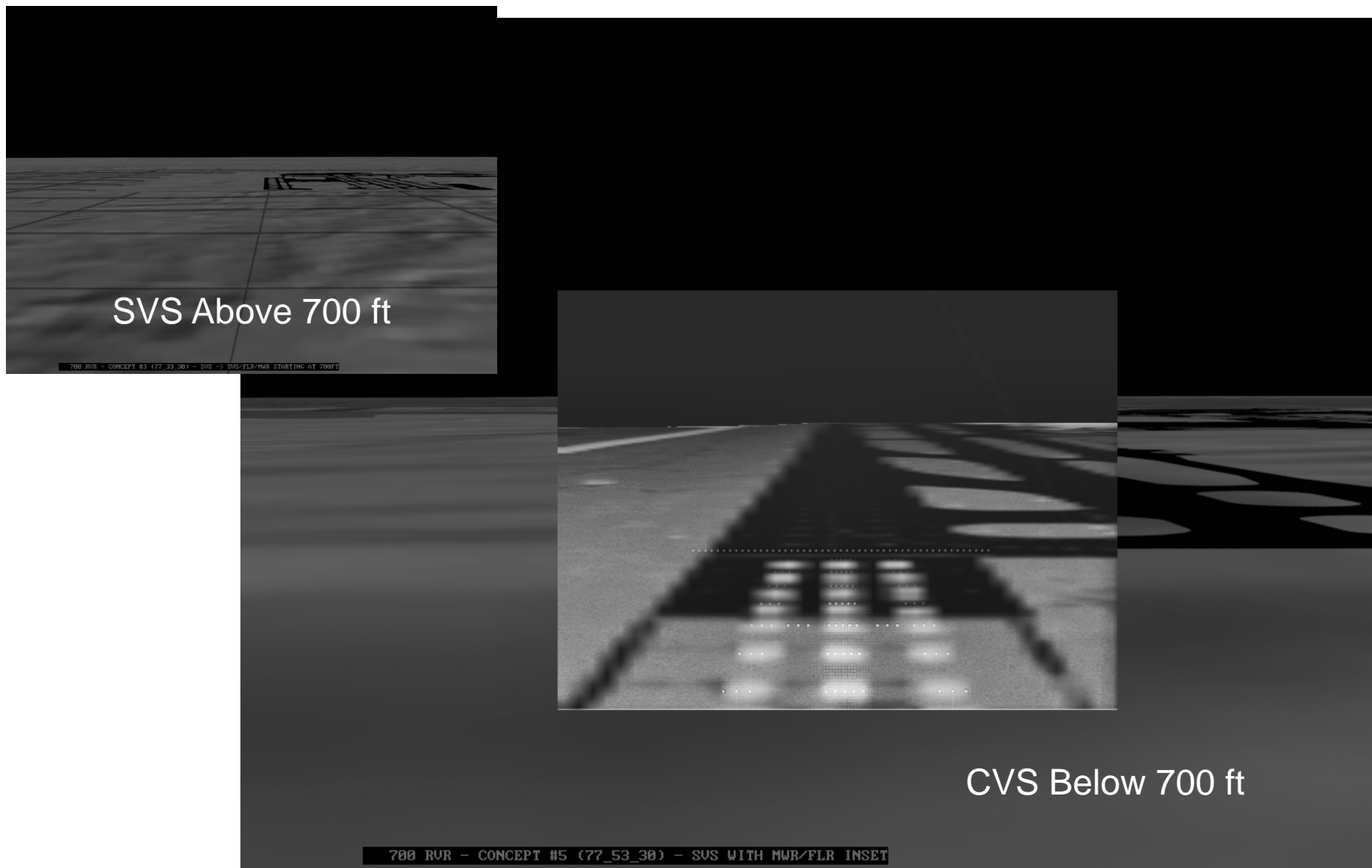


CVS Concept 2: Slant Range

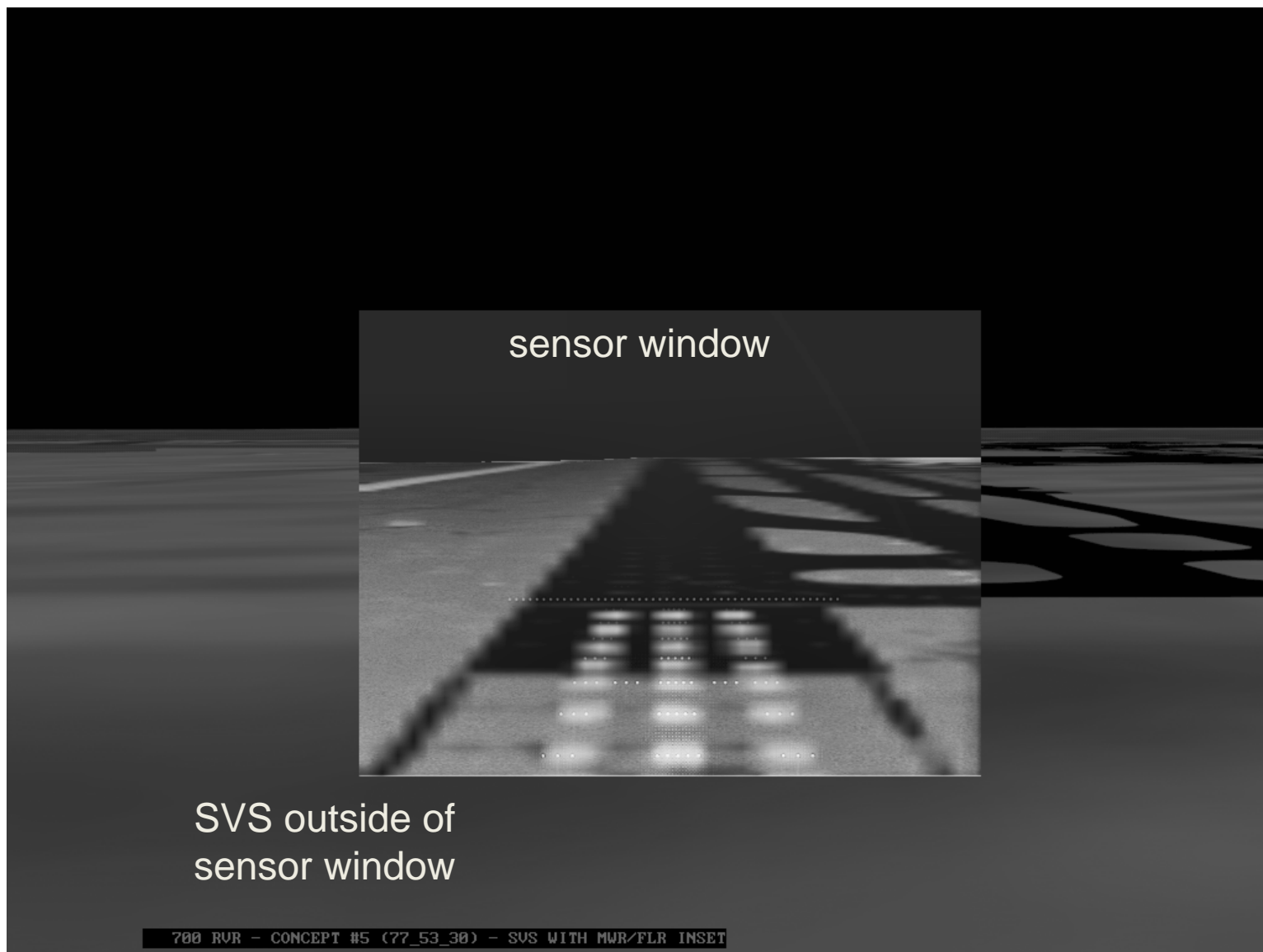
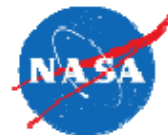




CVS Concept 3: SV with Timed Insertion of Blended EVS



CVS Concept 4: SV and Blended EVS



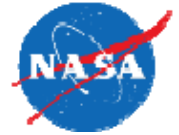
CVS Concept 5: SV and Slant Range EVS



SVS with MmW area when in
range and IR when in range



700 RUR - CONCEPT #4 (77_43_30) - SLANT RANGE SVS/FLR/MWR



Design & Methodology

- Crews performed approaches, departures, and taxi operations during the experiment. Following each scenario, pilots were administered a workload and post-run questionnaire.
- The Air Force Flight Technical Center (AFFTC) Workload scale was used to evaluate workload.

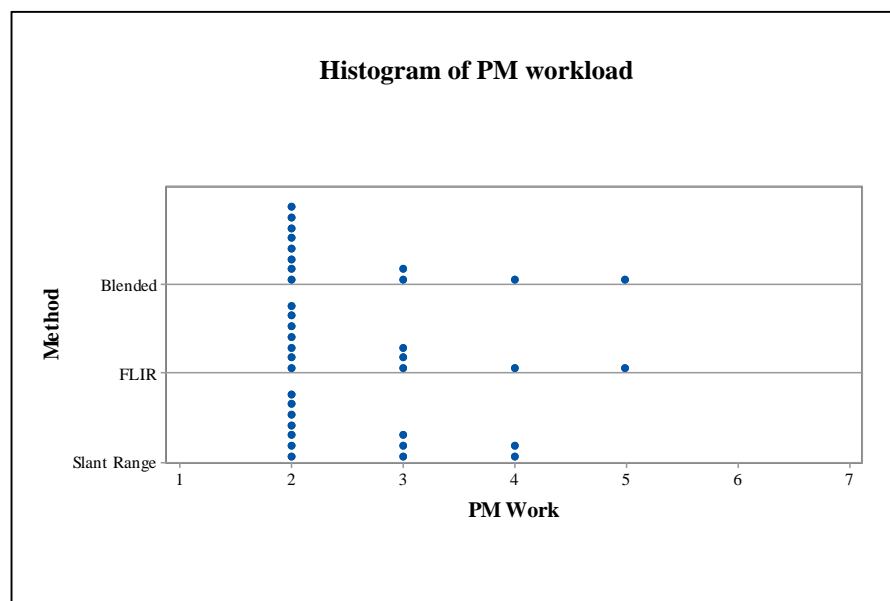
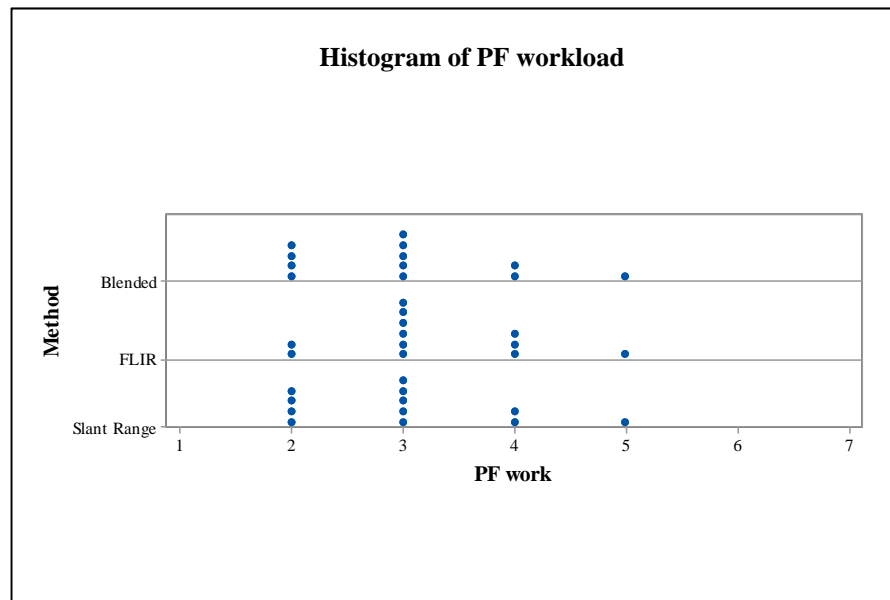
	<i>Workload Estimate</i>
1	Nothing To Do; No System Demands
2	Light Activity; Minimum Demands
3	Moderate Activity; Easily Managed; Considerable Spare Time
4	Busy; Challenging But Manageable; Adequate Time Available
5	Very Busy; Demanding To Manage; Barely Enough Time
6	Extremely Busy; Very Difficult; Non-Essential Tasks Postponed
7	Overloaded; System Unmanageable; Important Tasks Undone

- A series of six questions were administered as a part of the post-run questionnaire.
- Metrics of interest:
 - Pilot Workload
 - Co-Pilot Workload
 - Pilot Post-Run Ratings
 - Co-Pilot Post Run Ratings



Results: AFFTC Workload Ratings: Baseline Analysis

- Operational Baseline Analysis
 - Visibility: 1000 RVR
 - Methods:
 - FLIR (Baseline)
 - Blended
 - Slant Range
- No significant difference in Pilot Flying (PF) workload for CVS methodologies
 - Overall mean: 3.1-Workload was easily managed; spare time for other tasks
- No significant difference in Pilot Monitoring (PM) workload for CVS methodologies
 - Overall mean: 2.6-Workload was light to moderate; easily managed.





Results: Post-Run Ratings for Operational Baseline Analysis

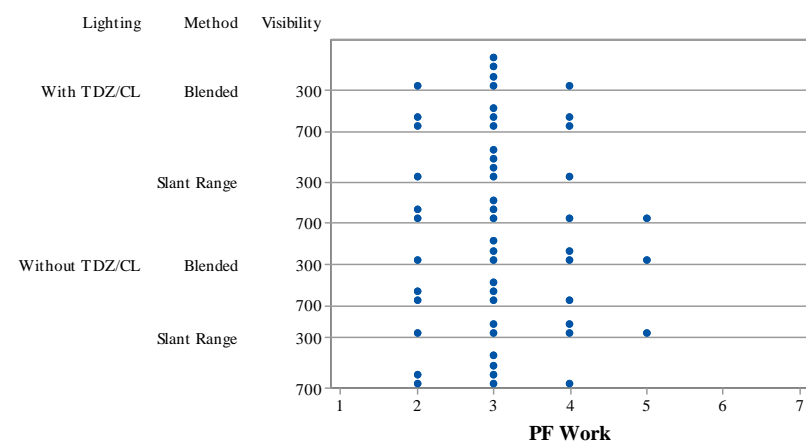
- Post-run ratings indicate the pilots agreed that with any of the vision system concepts (FLIR, Blended, Slant Range):
 - Able to safely land and complete the approach .
 - Able to maintain lateral alignment with the runway.
 - Visual cues provided sufficient cues to flare and land.
 - Allowed pilots sufficient time to recognize and identify visual references.
 - Landing visual references were visible and identifiable no lower than 100 ft AGL.
 - Provided the necessary visual references to continue the approach and landing.
- No significant differences in post-run ratings for these three vision system concepts.
 - All were usable for terminal operations in 1,000 ft RVR with no Touchdown Zone/Centerline (TDZ/CL) lights.



Results: AFFTC Workload Ratings: Blended vs. Slant Range

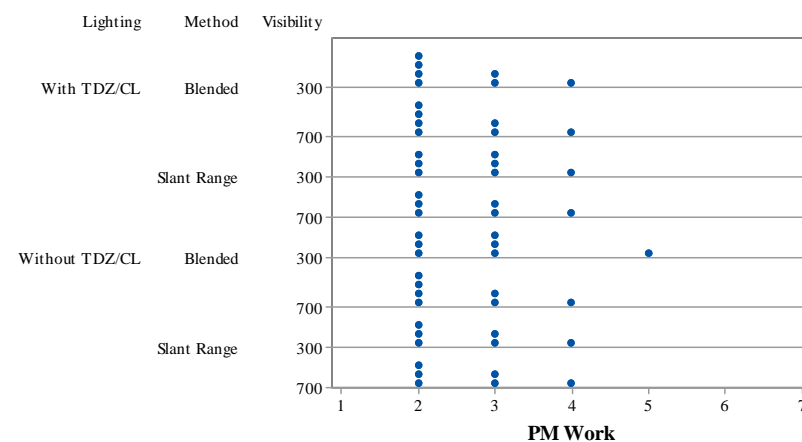
- Effect of Lighting, Visibility, and Method on Workload
- Lighting:
 - With/Without TDZ/CL lighting
- Visibility:
 - 700 RVR
 - 300 RVR
- Methods:
 - Blended
 - Slant Range
- No significant difference in PF workload when lighting, visibility, and method are varied.
 - Overall Mean: 3.08
- No significant difference in PM workload when lighting, visibility, and method are varied.
 - Overall Mean: 2.60
- PF reported a workload rating of 5 for 4 runs.
 - 3 of these 4 were without TDZ/CL lighting.
 - 3 of these 4 were with the slant range concept.
 - 3 of these 4 were under 300 RVR visibility

Histogram of PF workload



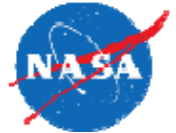
Each symbol represents up to 2 observations.

Histogram of PM workload



Each symbol represents up to 2 observations.

Results: Effects of Lighting, Visibility, CVS Method Post-Run Ratings



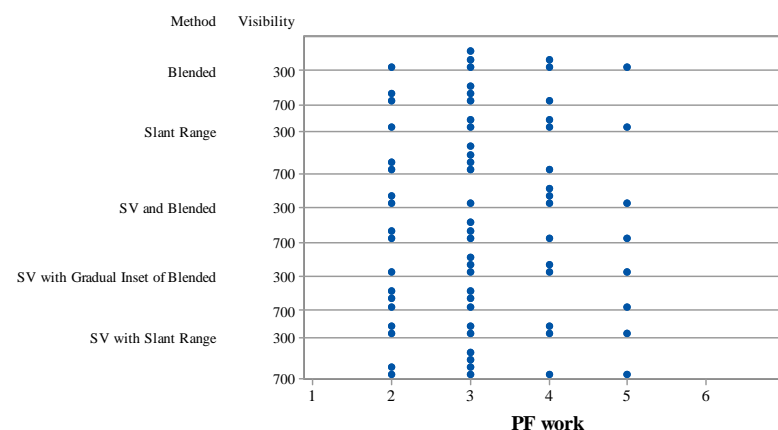
- With and without TDZ/CL light, at 300 ft RVR and 700 ft RVR, with either the Blended or Slant Range concept pilots were able to:
 - Safely land and complete the approach .
 - Maintain lateral alignment with the runway.
 - Pick up the visual cue for flare and landing.
 - Recognize and identify visual references.
 - Identify landing visual references no lower than 100 ft AGL.
 - Identify the necessary visual references to continue the approach and landing.
- Statistically significant differences in responses were found for:
 - PF ability to recognize and identify the required visual references under different visibilities
 - PM ability to detect the visual information for sufficient cues to flare and land with and without TDZ/CL lights
 - PM ability to maintain lateral alignment with the runway under 300 RVR and 700 RVR
 - None of these statistical differences were operationally significant.
- Pilots were able to safely conduct approach and landings with the vision system concepts in visibilities as low as 300 RVR, with and without TDZ/CL lights.



Results: AFFTC Workload Ratings: Adding Synthetic Vision

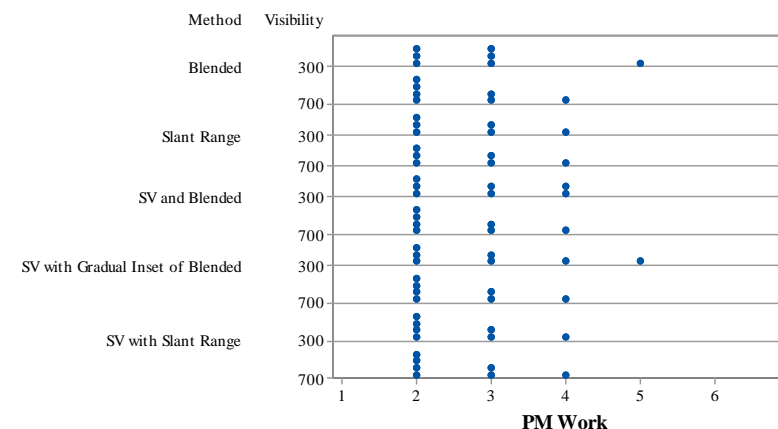
- Adding Synthetic Vision to the EFVS
- Visibility:
 - 700 RVR
 - 300 RVR
- Methods:
 - Blended
 - Slant Range,
 - SVS with Blended
 - SVS with Time Insertion of the Blended
 - SVS with Slant Rang
- There is a significant difference in PF workload in 300 RVR and 700 RVR
- No significant difference in PM workload when adding Synthetic Vision to the HUD.
 - Overall Mean: 2.62

Histogram of PF workload

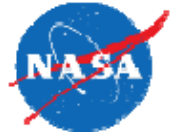


Each symbol represents up to 2 observations.

Histogram of PM workload



Each symbol represents up to 2 observations.



Tukey Pairwise Comparison on Visibility

- Tukey Pairwise Comparison investigated the difference in PF workload between visibility conditions
 - Pilots reported a lower workload under 700 RVR than under 300 RVR
 - 300 RVR mean: 3.32
 - 700 RVR mean: 2.92
 - Although these means are statistically different, the difference is not operationally significant.
- No significant second-order effects.

Results: Effects of adding Synthetic Vision to the EFVS Post-Run Ratings



- Without TDZ/CL light, at 300 ft RVR and 700 ft RVR, with any of the 5 concepts, pilots were able to:
 - Safely land and complete the approach .
 - Maintain lateral alignment with the runway.
 - Pick up the visual cue for flare and landing.
 - Recognize and identify visual references.
 - Identify landing visual references no lower than 100 ft AGL.
 - Identify the necessary visual references to continue the approach and landing.
- Visibility had a significant effect on pilot ratings of:
 - Ability to recognize and identify required visual references and detecting visual information for cues for flare and landing.
 - Having sufficient time to recognize and identify the required visual references.
 - Ability to maintain lateral alignment with the runway
 - None of these statistical differences were operationally significant.
- Post-run ratings indicate that pilots agreed that they were able to conduct approach and landing operations in visibilities as low as 300 RVR with all five of the vision system concepts

Conclusions



- Pilots stated that all five vision system concepts were usable for terminal operations in visibilities as low as 300 RVR.
- With a dual sensor Enhanced Vision System, pilots can perform approach and landing operations in visibilities as low as 300 RVR without any workload penalty.



Thank you!

Questions?

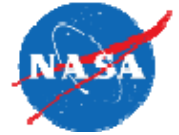


Back Up Slides

Post-Run Approach Questions



Post-Run APPROACH Ratings	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree or Disagree	Slightly Agree	Agree	Strongly Agree
Please rate your agreement with each statements based on HUD EFVS concept you just evaluated.	1	2	3	4	5	6	7
Q1. Prior to DH, I was able to pick up the necessary visual references to continue the approach or landing.							
Q2. The landing visual references were visible and identifiable no lower than 100 ft AFL (i.e., the runway and touchdown zone).							
Q3. There was sufficient time to recognize and identify the required visual references.							
Q4. The visual information provided sufficient cues to flare and land.							
Q5. I was able to maintain lateral alignment with the runway.							
Q6. I was able to complete the approach and land safely.							



ANOVA Results: Baseline Workload

General Linear Model: PF work versus Method

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	0.5000	0.2500	0.29	0.749
Error	33	28.2500	0.8561		
Total	35	28.7500			

General Linear Model: PM Work versus Method

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	0.0556	0.02778	0.03	0.968
Error	33	28.5000	0.86364		
Total	35	28.5556			

Both PF and PM reported moderate activity, easily managed, and considerable spare time for tasks with respect to workload.



Results: Operational Baseline Q1

General Linear Model: PF Q1 versus Method

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	1.722	0.8611	1.26	0.296
Error	33	22.500	0.6818		
Total	35	24.222			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.825723	7.11%	1.48%	0.00%

General Linear Model: PM Q1 versus Method

Analysis of Variance

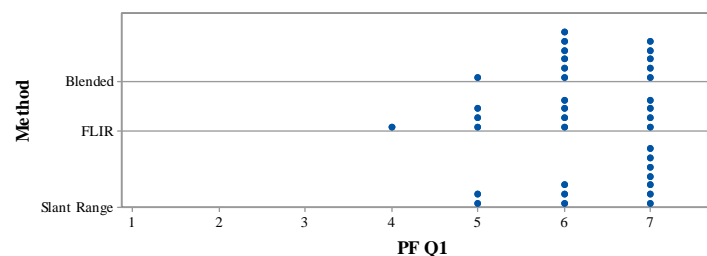
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	2.389	1.194	1.06	0.358
Error	33	37.167	1.126		
Total	35	39.556			

Model Summary

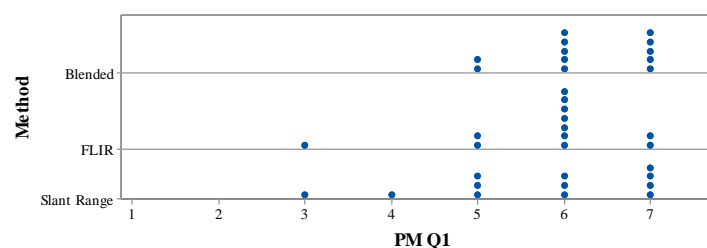
S	R-sq	R-sq(adj)	R-sq(pred)
1.06126	6.04%	0.34%	0.00%

Conclusions: No significant differences in the pilots ability to identify the necessary visual references to continue the approach and landing give one of the sensors.

Histogram of PF Q1



Histogram of PM Q1



Descriptive Statistics: PF Q1, PM Q1

Variable	N	Mean	StDev	Minimum	Maximum
PF Q1	36	6.222	0.832	4.000	7.000
PM Q1	36	5.889	1.063	3.000	7.000



Results: Operational Baseline Q3

General Linear Model: PM Q3 versus Method

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	1.167	0.5833	0.88	0.424
Error	33	21.833	0.6616		
Total	35	23.000			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.813398	5.07%	0.00%	0.00%

General Linear Model: PF Q3 versus Method

Analysis of Variance

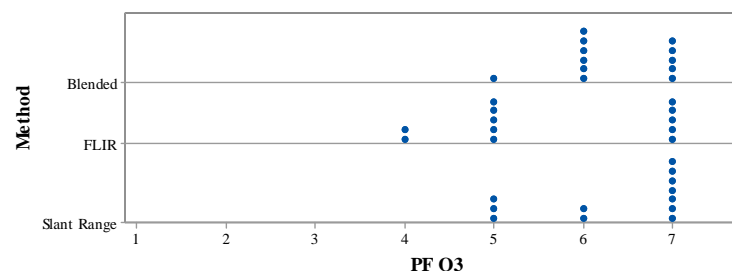
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	3.556	1.7778	1.96	0.158
Error	33	30.000	0.9091		
Total	35	33.556			

Model Summary

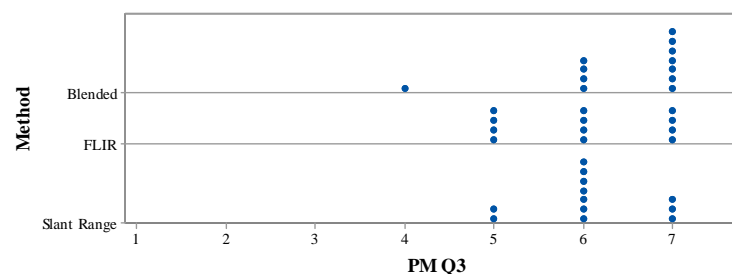
S	R-sq	R-sq(adj)	R-sq(pred)
0.953463	10.60%	5.18%	0.00%

Conclusion: No significant difference in sufficiency of time to recognize and identify the required visual references for any of the three methods.

Histogram of PF Q3



Histogram of PM Q3



Descriptive Statistics: PF Q3, PM Q3

Variable	N	Mean	StDev	Minimum	Maximum
PF Q3	36	6.111	0.979	4.000	7.000
PM Q3	36	6.167	0.811	4.000	7.000

Results: Operational Baseline Q4



General Linear Model: PF Q4 versus Method

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	0.3889	0.1944	0.37	0.692
Error	33	17.2500	0.5227		
Total	35	17.6389			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.722999	2.20%	0.00%	0.00%

Descriptive Statistics: PF Q4, PM Q4

Variable	N	Mean	StDev	Minimum	Maximum
PF Q4	36	6.306	0.710	5.000	7.000
PM Q4	36	6.194	0.856	3.000	7.000

General Linear Model: PM Q4 versus Method

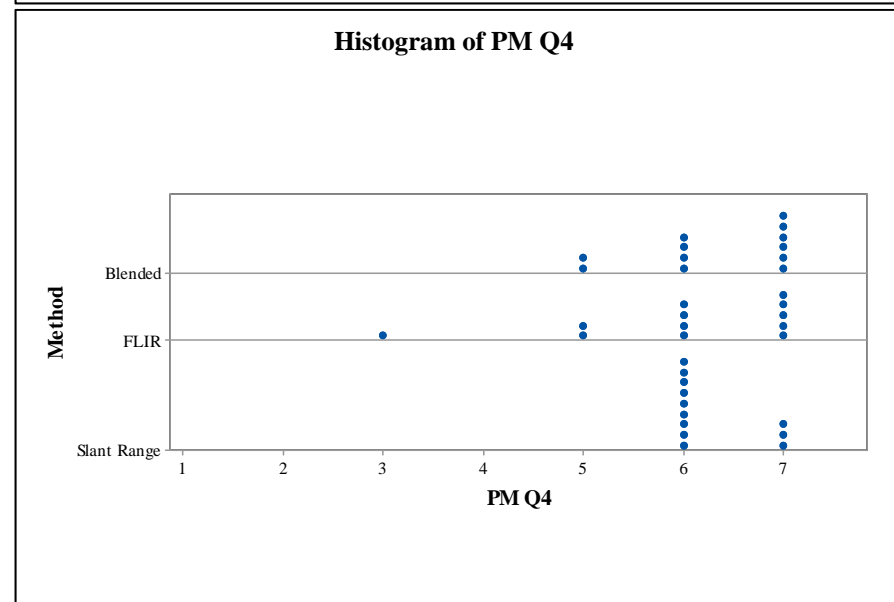
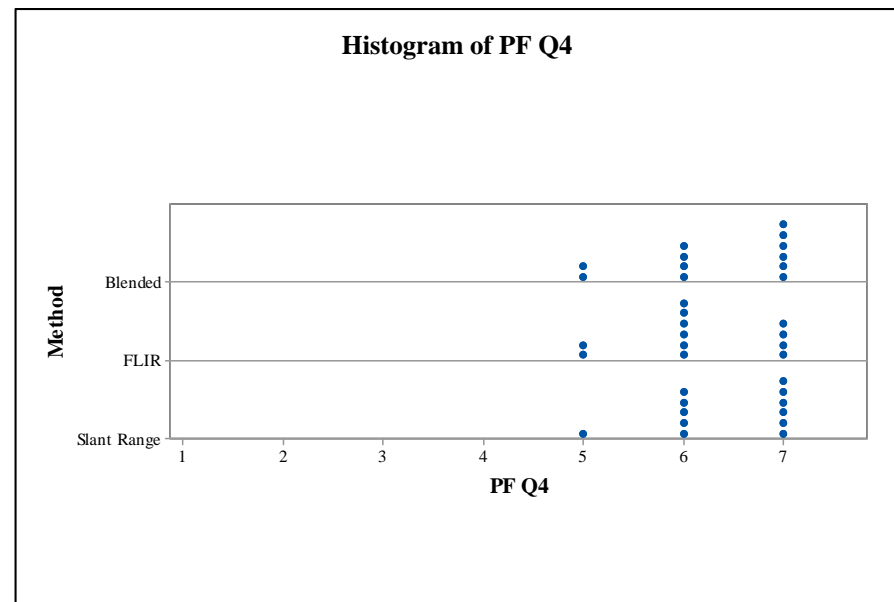
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	0.7222	0.3611	0.48	0.624
Error	33	24.9167	0.7551		
Total	35	25.6389			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.868936	2.82%	0.00%	0.00%

Conclusion: No significant difference in the pilots (PF or PM) ability detect visual information providing cues for flare and landing given any of the 3 methods.





Results: Operational Baseline Q5

General Linear Model: PF Q5 versus Method

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	0.3889	0.1944	0.51	0.603
Error	33	12.5000	0.3788		
Total	35	12.8889			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.615457	3.02%	0.00%	0.00%

Descriptive Statistics: PF Q5, PM Q5

Variable	N	Mean	StDev	Minimum	Maximum
PF Q5	36	6.444	0.607	5.000	7.000
PM Q5	36	6.444	0.607	5.000	7.000

General Linear Model: PM Q5 versus Method

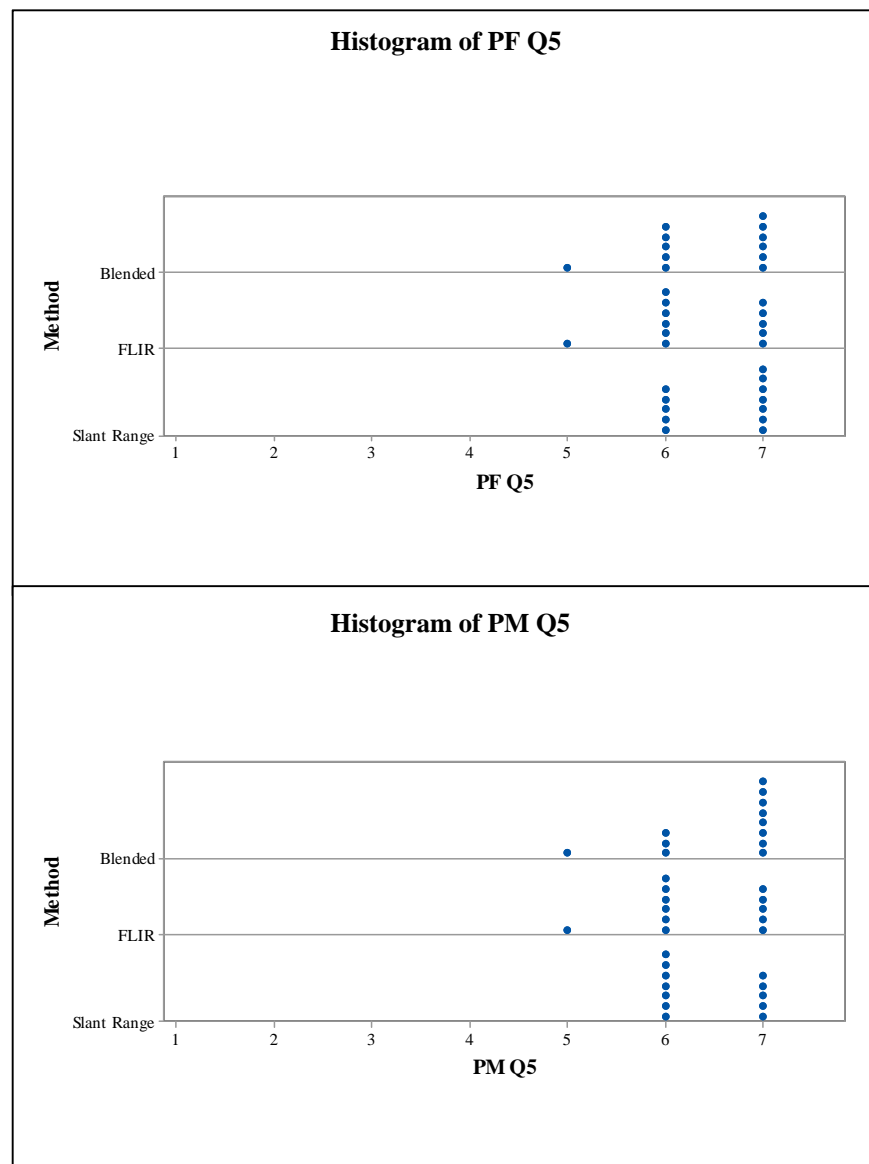
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	0.3889	0.1944	0.51	0.603
Error	33	12.5000	0.3788		
Total	35	12.8889			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.615457	3.02%	0.00%	0.00%

Conclusion: No significant difference in pilots (PF or PM) ability to maintain lateral alignment with the runway when provided with any one of the three imaging sensors.





Results: Operational Baseline Q6

General Linear Model: PF Q6 versus Method

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	1.167	0.5833	1.66	0.205
Error	33	11.583	0.3510		
Total	35	12.750			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.592461	9.15%	3.64%	0.00%

Descriptive Statistics: PF Q6, PM Q6

Variable	N	Mean	StDev	Minimum	Maximum
PF Q6	36	6.583	0.604	5.000	7.000
PM Q6	36	6.472	0.654	5.000	7.000

General Linear Model: PM Q6 versus Method

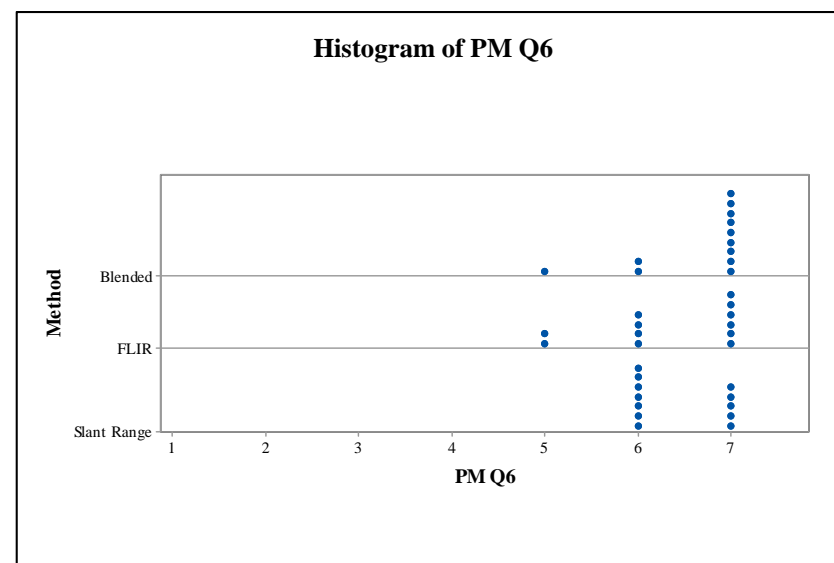
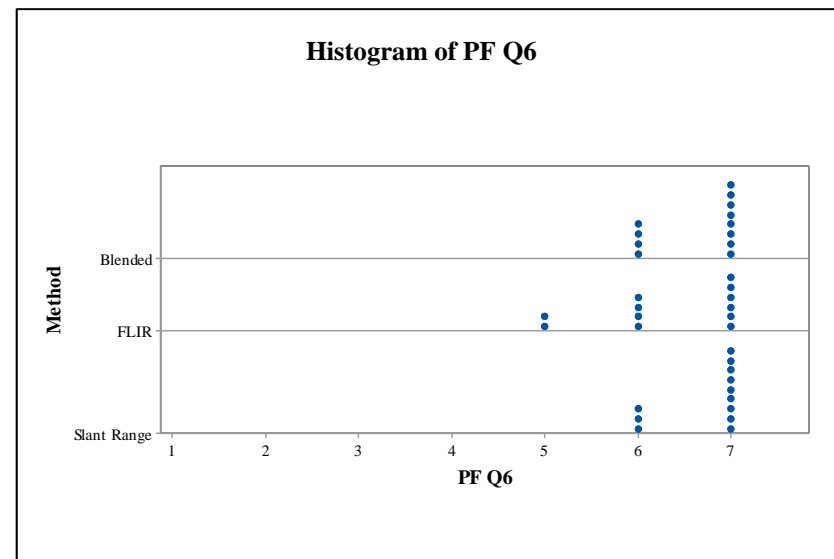
Analysis of Variance

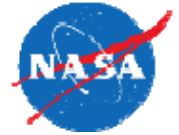
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	2	0.7222	0.3611	0.84	0.442
Error	33	14.2500	0.4318		
Total	35	14.9722			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.657129	4.82%	0.00%	0.00%

Conclusion: No significant difference in the pilots ability to complete the approach and landing safely for all methodologies.





Descriptive Statistics: Operational Baseline

Variable	Method	N	Mean	StDev	Minimum	Maximum							
PF Q1	Blended	12	6.333	0.651	5.000	7.000	PM Q1	Blended	12	6.250	0.754	5.000	7.000
	FLIR	12	5.917	0.996	4.000	7.000		FLIR	12	5.750	1.055	3.000	7.000
	Slant Range	12	6.417	0.793	5.000	7.000		Slant Range	12	5.667	1.303	3.000	7.000
PF Q2	Blended	12	6.083	1.379	2.000	7.000	PM Q2	Blended	12	6.417	0.669	5.000	7.000
	FLIR	12	5.667	1.557	2.000	7.000		FLIR	12	5.833	0.577	5.000	7.000
	Slant Range	12	5.917	1.443	2.000	7.000		Slant Range	12	6.083	0.793	5.000	7.000
PF Q3	Blended	12	6.333	0.651	5.000	7.000	PM Q3	Blended	12	6.417	0.900	4.000	7.000
	FLIR	12	5.667	1.231	4.000	7.000		FLIR	12	6.000	0.853	5.000	7.000
	Slant Range	12	6.333	0.888	5.000	7.000		Slant Range	12	6.083	0.669	5.000	7.000
PF Q4	Blended	12	6.333	0.778	5.000	7.000	PM Q4	Blended	12	6.333	0.778	5.000	7.000
	FLIR	12	6.167	0.718	5.000	7.000		FLIR	12	6.000	1.206	3.000	7.000
	Slant Range	12	6.417	0.669	5.000	7.000		Slant Range	12	6.250	0.452	6.000	7.000
PF Q5	Blended	12	6.417	0.669	5.000	7.000	PM Q5	Blended	12	6.583	0.669	5.000	7.000
	FLIR	12	6.333	0.651	5.000	7.000		FLIR	12	6.333	0.651	5.000	7.000
	Slant Range	12	6.583	0.515	6.000	7.000		Slant Range	12	6.417	0.515	6.000	7.000
PF Q6	Blended	12	6.667	0.492	6.000	7.000	PM Q6	Blended	12	6.667	0.651	5.000	7.000
	FLIR	12	6.333	0.778	5.000	7.000		FLIR	12	6.333	0.778	5.000	7.000
	Slant Range	12	6.750	0.452	6.000	7.000		Slant Range	12	6.417	0.515	6.000	7.000



Operational Baseline Analysis Conclusions

- Conclusions:
 - Pilots were able to safely land and complete the approach with any of the 3 sensors.
 - Pilots were able to maintain lateral alignment with the runway when provided with one of the three imaging sensors.
 - The visual cues provided sufficient cues to flare and land given any of the three concepts.
 - All 3 concepts allowed the pilots sufficient time to recognize and identify the required visual references.
 - Given any of the 3 display concepts, the landing visual references were visible and identifiable no lower than 100 ft AGL
 - At 1,000 ft RVR with no TDZ/CL lights, all 3 display concepts provided the necessary visual references to continue the approach and landing.



ANOVA: Effects of Lighting and Visibility and CVS Method on Workload

General Linear Model: PF Work versus Lighting, Method, Visibility

Analysis of Variance

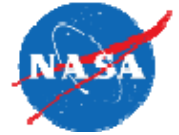
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Lighting	1	0.3750	0.37500	0.62	0.433
Method	1	0.1667	0.16667	0.28	0.601
Visibility	1	1.5000	1.50000	2.48	0.119
Lighting*Method	1	0.0417	0.04167	0.07	0.793
Lighting*Visibility	1	2.0417	2.04167	3.38	0.069
Method*Visibility	1	0.0000	0.00000	0.00	1.000
Lighting*Method*Visibility	1	0.0417	0.04167	0.07	0.793
Error	88	53.1667	0.60417		
Total	95	57.3333			

There were no significant differences between the main factors, Lighting, Visibility, and Method, or their second-order interactions.

General Linear Model: PM Work versus Lighting, Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Lighting	1	0.1667	0.16667	0.30	0.582
Method	1	0.1667	0.16667	0.30	0.582
Visibility	1	0.0417	0.04167	0.08	0.783
Lighting*Method	1	0.0417	0.04167	0.08	0.783
Lighting*Visibility	1	0.1667	0.16667	0.30	0.582
Method*Visibility	1	0.1667	0.16667	0.30	0.582
Lighting*Method*Visibility	1	0.0417	0.04167	0.08	0.783
Error	88	48.1667	0.54735		
Total	95	48.9583			



Results: Effects of Lighting and Visibility on CVS Method Q1

General Linear Model: PF Q1 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.3750	0.37500	0.46	0.498
Visibility	1	1.5000	1.50000	1.85	0.177
Lighting	1	2.0417	2.04167	2.52	0.116
Method*Visibility	1	0.0417	0.04167	0.05	0.821
Method*Lighting	1	0.0000	0.00000	0.00	1.000
Visibility*Lighting	1	2.0417	2.04167	2.52	0.116
Method*Visibility*Lighting	1	0.0000	0.00000	0.00	1.000
Error	88	71.3333	0.81061		
Total	95	77.3333			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.900337	7.76%	0.42%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

General Linear Model: PM Q1 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.000	0.00000	0.00	1.000
Visibility	1	0.042	0.04167	0.04	0.848
Lighting	1	1.500	1.50000	1.32	0.253
Method*Visibility	1	0.000	0.00000	0.00	1.000
Method*Lighting	1	1.042	1.04167	0.92	0.340
Visibility*Lighting	1	2.667	2.66667	2.35	0.129
Method*Visibility*Lighting	1	0.042	0.04167	0.04	0.848
Error	88	99.667	1.13258		
Total	95	104.958			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.06423	5.04%	0.00%	0.00%

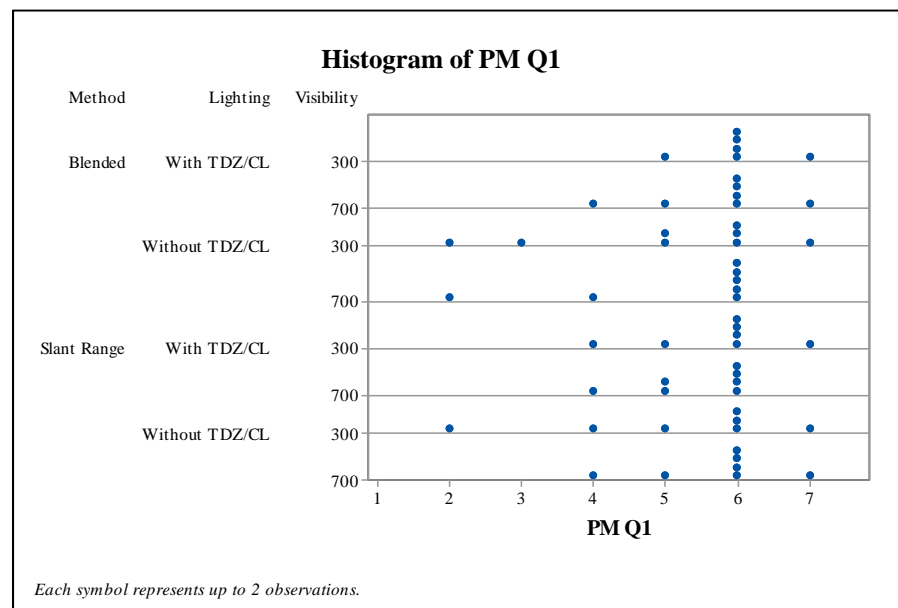
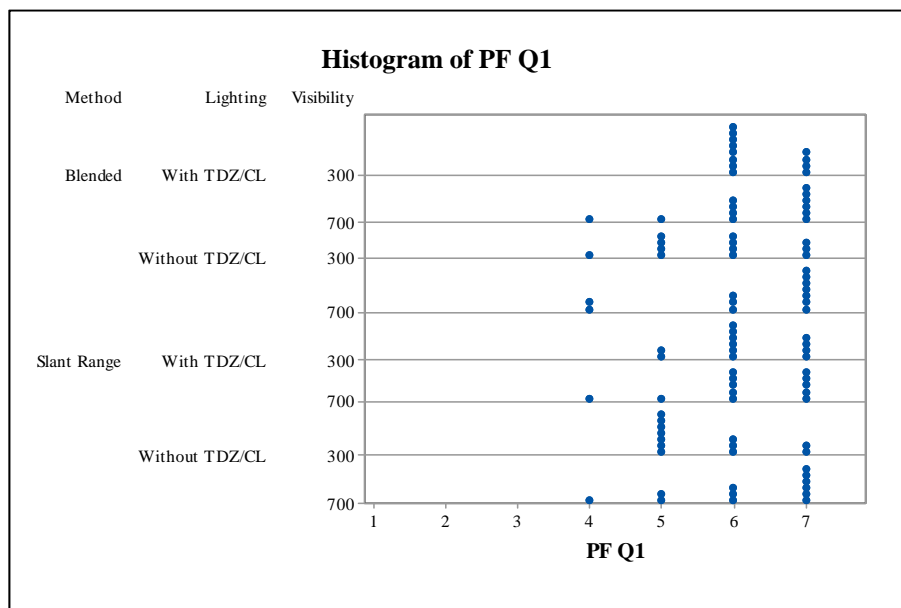
Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

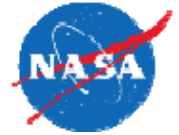


Results: Effects of Lighting and Visibility on CVS Method Q1

Descriptive Statistics: PF Q1, PM Q1

Variable	N	Mean	StDev	Minimum	Maximum
PF Q1	96	6.0833	0.9022	4.0000	7.0000
PM Q1	96	5.604	1.051	2.000	7.000





Results: Effects of Lighting and Visibility on CVS Method Q2

General Linear Model: PF Q2 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.000	0.00000	0.00	1.000
Visibility	1	2.042	2.04167	1.56	0.214
Lighting	1	0.375	0.37500	0.29	0.593
Method*Visibility	1	0.167	0.16667	0.13	0.722
Method*Lighting	1	0.167	0.16667	0.13	0.722
Visibility*Lighting	1	2.042	2.04167	1.56	0.214
Method*Visibility*Lighting	1	0.000	0.00000	0.00	1.000
Error	88	114.833	1.30492		
Total	95	119.625			

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.14233	4.01%	0.00%	0.00%

General Linear Model: PM Q2 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.3750	0.37500	0.64	0.425
Visibility	1	0.0417	0.04167	0.07	0.790
Lighting	1	0.6667	0.66667	1.14	0.288
Method*Visibility	1	0.1667	0.16667	0.29	0.594
Method*Lighting	1	0.0417	0.04167	0.07	0.790
Visibility*Lighting	1	0.0417	0.04167	0.07	0.790
Method*Visibility*Lighting	1	0.6667	0.66667	1.14	0.288
Error	88	51.3333	0.58333		
Total	95	53.3333			

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

Model Summary

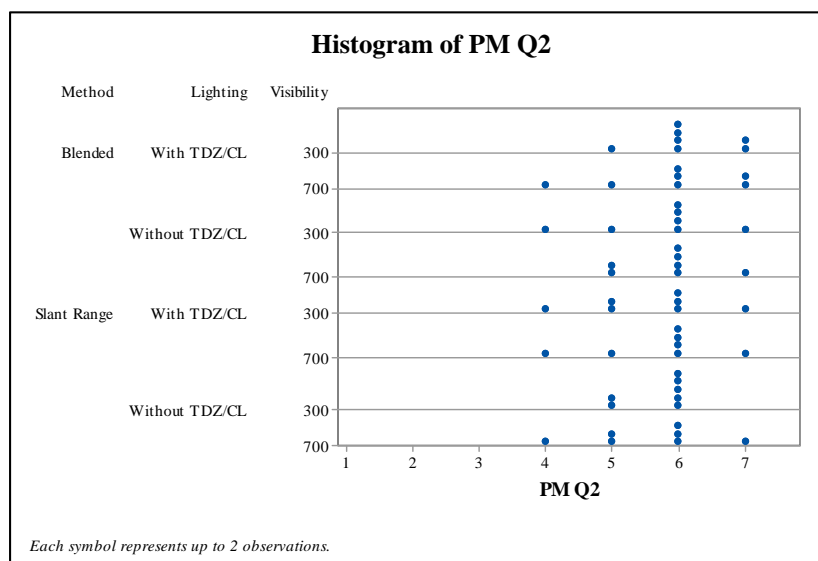
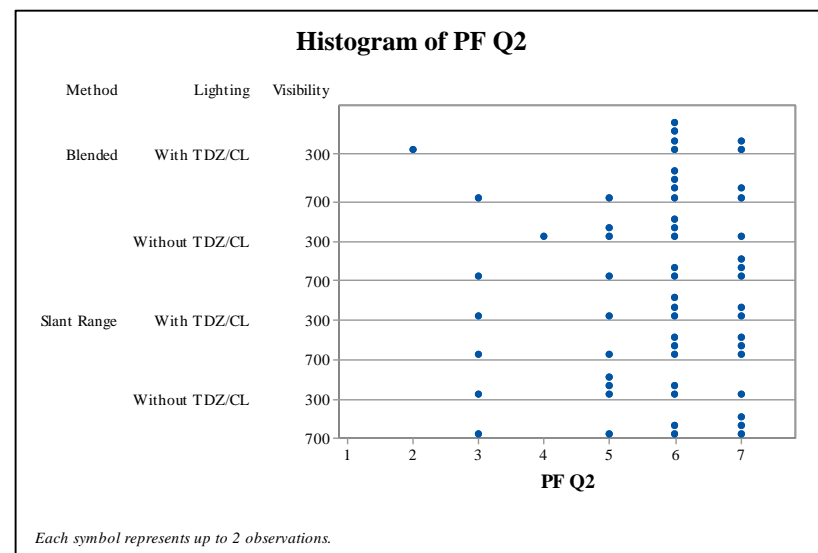
S	R-sq	R-sq(adj)	R-sq(pred)
0.763763	3.75%	0.00%	0.00%



Results: Effects of Lighting and Visibility on CVS Method Q2

Descriptive Statistics: PF Q2, PM Q2

Variable	N	Mean	StDev	Minimum	Maximum
PF Q2	96	5.938	1.122	2.000	7.000
PM Q2	96	5.8333	0.7493	4.0000	7.0000





Results: Effects of Lighting and Visibility on CVS Method Q3

General Linear Model: PF Q3 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.1667	0.16667	0.26	0.612
Visibility	1	4.1667	4.16667	6.47	0.013
Lighting	1	1.0417	1.04167	1.62	0.207
Method*Visibility	1	0.0000	0.00000	0.00	1.000
Method*Lighting	1	0.0417	0.04167	0.06	0.800
Visibility*Lighting	1	3.3750	3.37500	5.24	0.024
Method*Visibility*Lighting	1	0.3750	0.37500	0.58	0.447
Error	88	56.6667	0.64394		
Total	95	65.8333			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.802458	13.92%	7.08%	0.00%

Conclusion: Visibility was significant. Second-order interaction between visibility and lighting was significant. Differences were not operationally significant.

General Linear Model: PM Q3 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.6667	0.66667	1.24	0.269
Visibility	1	0.0000	0.00000	0.00	1.000
Lighting	1	0.1667	0.16667	0.31	0.579
Method*Visibility	1	0.0417	0.04167	0.08	0.781
Method*Lighting	1	0.0417	0.04167	0.08	0.781
Visibility*Lighting	1	0.0417	0.04167	0.08	0.781
Method*Visibility*Lighting	1	0.6667	0.66667	1.24	0.269
Error	88	47.3333	0.537879		
Total	95	48.9583			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.733402	3.32%	0.00%	0.00%

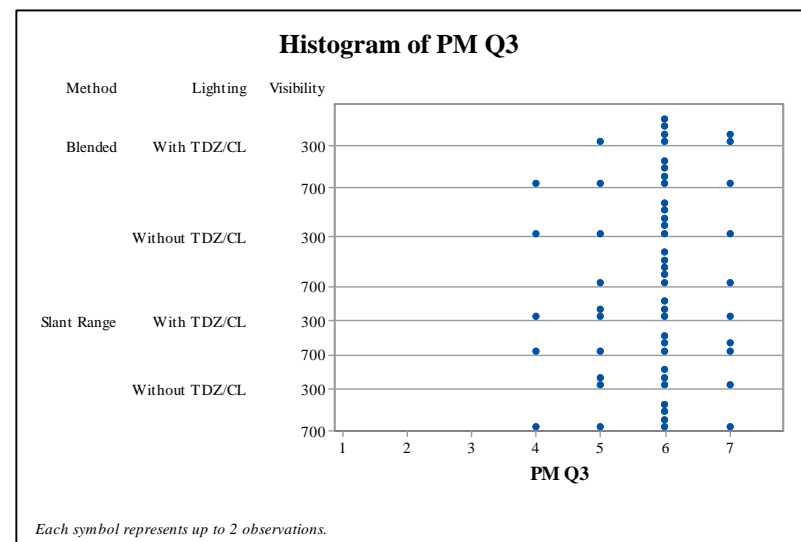
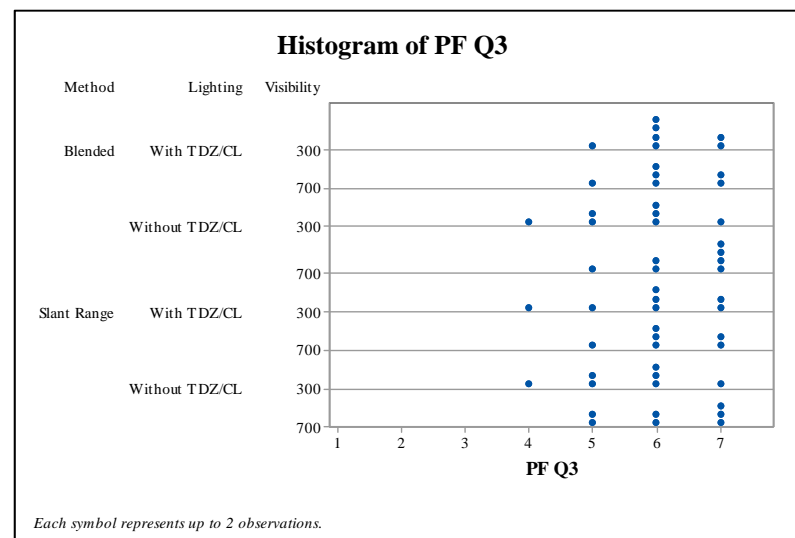
Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

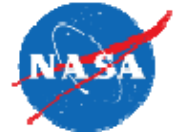


Results: Effects of Lighting and Visibility on CVS Method Q3

Descriptive Statistics: PF Q3, PM Q3

Variable	N	Mean	StDev	Minimum	Maximum
PF Q3	96	6.0417	0.8325	4.0000	7.0000
PM Q3	96	5.8958	0.7179	4.0000	7.0000





Effects PF Q3

- PF Q3: Main Effect for Visibility
 - Significant Difference between 700 RVR and 300 RVR

Visibility	N	Mean	Grouping
700	48	6.25000	A
300	48	5.83333	B

Means that do not share a letter are significantly different.

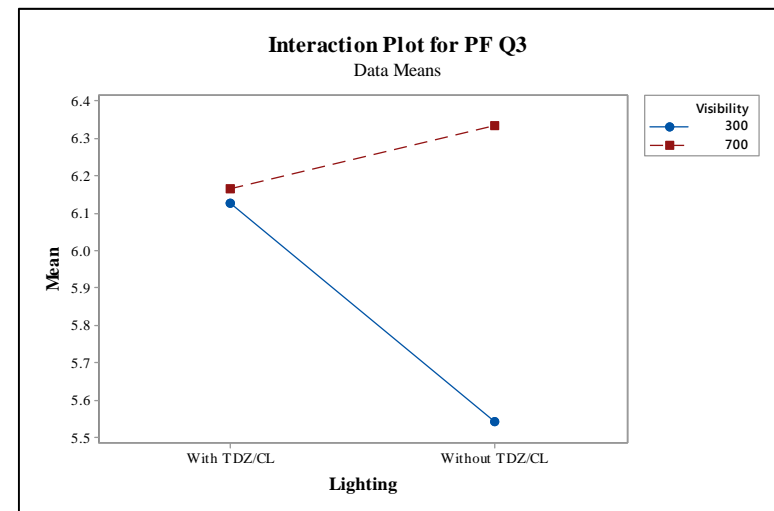
- PF Q3: Secondary Effect for Visibility*Lighting
 - Significant Difference between:
 - 700 Without TDZ/CL and 300 without TDZ/CL
 - 700 With TDZ/CL and 300 without TDZ/CL

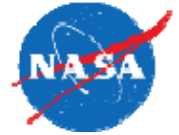
Tukey Pairwise Comparisons: Response = PF Q3, Term = Visibility*Lighting

Grouping Information Using the Tukey Method and 95% Confidence

Visibility*Lighting	N	Mean	Grouping
700 Without TDZ/CL	24	6.33333	A
700 With TDZ/CL	24	6.16667	A
300 With TDZ/CL	24	6.12500	A B
300 Without TDZ/CL	24	5.54167	B

Means that do not share a letter are significantly different.





Results: Effects of Lighting and Visibility on CVS Method Q4

General Linear Model: PF Q4 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.0104	0.01042	0.02	0.880
Visibility	1	6.5104	6.51042	14.41	0.000
Lighting	1	0.8437	0.84375	1.87	0.175
Method*Visibility	1	0.0104	0.01042	0.02	0.880
Method*Lighting	1	0.0937	0.09375	0.21	0.650
Visibility*Lighting	1	3.7604	3.76042	8.32	0.005
Method*Visibility*Lighting	1	0.2604	0.26042	0.58	0.450
Error	88	39.7500	0.45170		
Total	95	51.2396			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.672090	22.42%	16.25%	7.68%

Conclusion: Visibility was significant. Second-order interaction between visibility and lighting was significant. Differences were not operationally significant.

General Linear Model: PM Q4 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.0104	0.01042	0.02	0.899
Visibility	1	0.8437	0.84375	1.32	0.254
Lighting	1	3.7604	3.76042	5.87	0.017
Method*Visibility	1	0.0104	0.01042	0.02	0.899
Method*Lighting	1	0.0937	0.09375	0.15	0.703
Visibility*Lighting	1	2.3437	2.34375	3.66	0.059
Method*Visibility*Lighting	1	0.5104	0.51042	0.80	0.375
Error	88	56.4167	0.64110		
Total	95	63.9896			

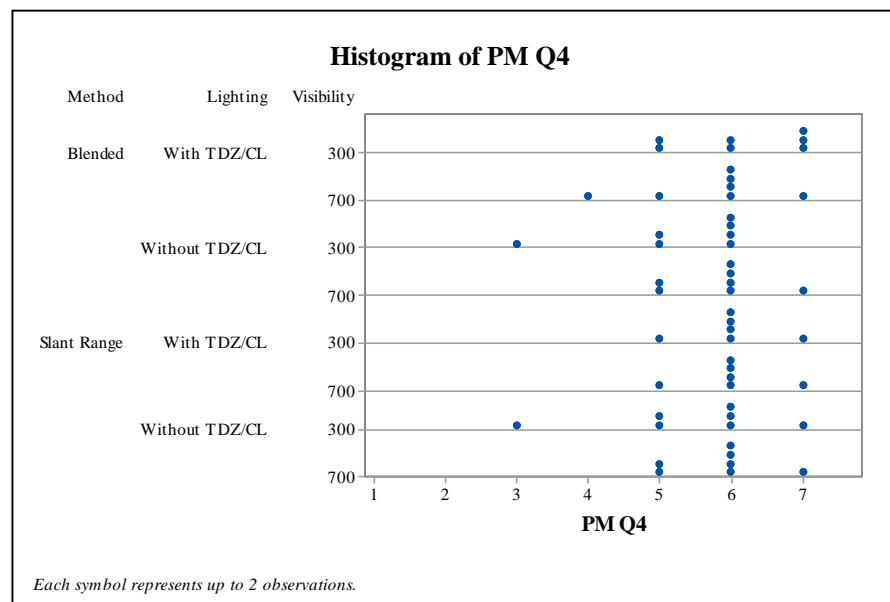
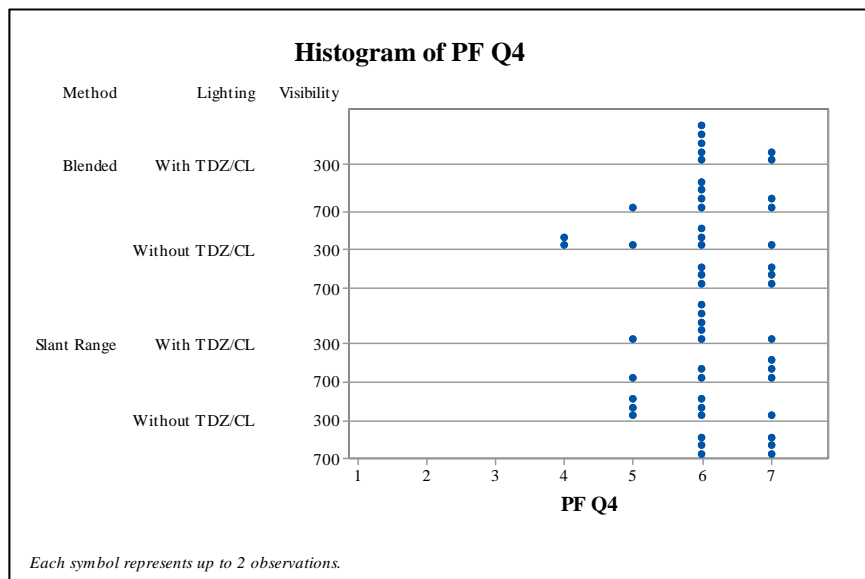
Model Summary

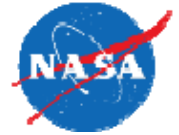
S	R-sq	R-sq(adj)	R-sq(pred)
0.800686	11.83%	4.82%	0.00%

Conclusion: Lighting was significant. No significant second-order interactions. Difference was not operationally significant.



Results: Effects of Lighting and Visibility on CVS Method Q4





Effects PF Q4

- PF Q4: Main Effect for Visibility
 - Significant Difference between 700 RVR and 300 RVR

Tukey Pairwise Comparisons: Response = PF Q4, Term = Visibility

Grouping Information Using the Tukey Method and 95% Confidence

Visibility	N	Mean	Grouping
700	48	6.39583	A
300	48	5.87500	B

Means that do not share a letter are significantly different.

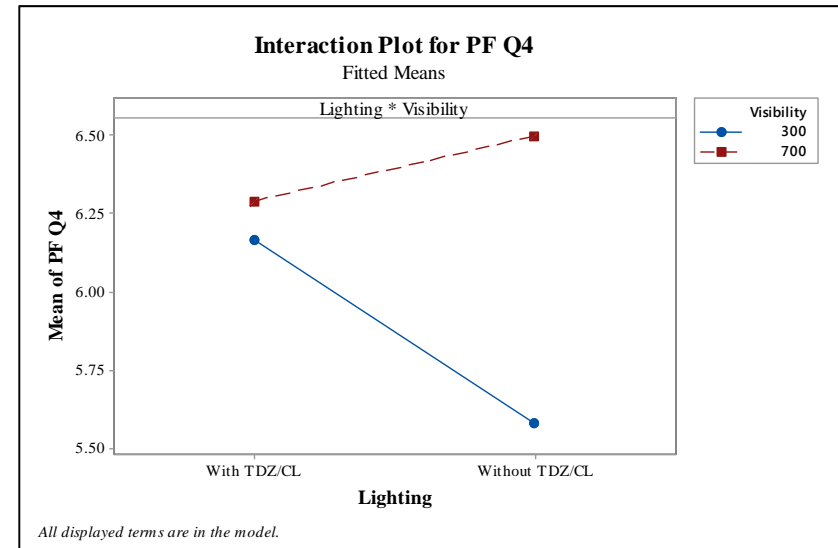
- PF Q4: Secondary Effect for Visibility*Lighting
 - Significant Difference between:
 - 300 without TDZ/CL and 300 with TDZ/CL
 - 700 with TDZ/CL and 300 without TDZ/CL
 - 700 without TDZ/CL and 300 without TDZ/CL

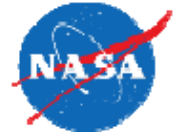
Tukey Pairwise Comparisons: Response = PF Q4, Term = Visibility*Lighting

Grouping Information Using the Tukey Method and 95% Confidence

Visibility*Lighting	N	Mean	Grouping
700 Without TDZ/CL	24	6.50000	A
700 With TDZ/CL	24	6.29167	A
300 With TDZ/CL	24	6.16667	A
300 Without TDZ/CL	24	5.58333	B

Means that do not share a letter are significantly different.





Effects PM Q4

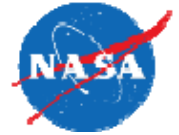
- PM Q4: Main Effect for Lighting
 - Significant Difference between with TDZ/CL and without TDZ/CL

Tukey Pairwise Comparisons: Response = PM Q4, Term = Lighting

Grouping Information Using the Tukey Method and 95% Confidence

Lighting	N	Mean	Grouping
With TDZ/CL	48	6.02083	A
Without TDZ/CL	48	5.62500	B

Means that do not share a letter are significantly different.



Results: Effects of Lighting and Visibility on CVS Method Q5

General Linear Model: PF Q5 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.0104	0.01042	0.03	0.862
Visibility	1	0.2604	0.26042	0.76	0.386
Lighting	1	0.2604	0.26042	0.76	0.386
Method*Visibility	1	0.0937	0.09375	0.27	0.603
Method*Lighting	1	0.0104	0.01042	0.03	0.862
Visibility*Lighting	1	0.8438	0.84375	2.45	0.121
Method*Visibility*Lighting	1	0.0104	0.01042	0.03	0.862
Error	88	30.2500	0.34375		
Total	95	31.7396			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.586302	4.69%	0.00%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

General Linear Model: PM Q5 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.0104	0.01042	0.02	0.887
Visibility	1	2.3437	2.34375	4.59	0.035
Lighting	1	1.7604	1.76042	3.45	0.067
Method*Visibility	1	0.0937	0.09375	0.18	0.669
Method*Lighting	1	0.0104	0.01042	0.02	0.887
Visibility*Lighting	1	2.3437	2.34375	4.59	0.035
Method*Visibility*Lighting	1	0.2604	0.26042	0.51	0.477
Error	88	44.9167	0.51042		
Total	95	51.7396			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.714435	13.19%	6.28%	0.00%

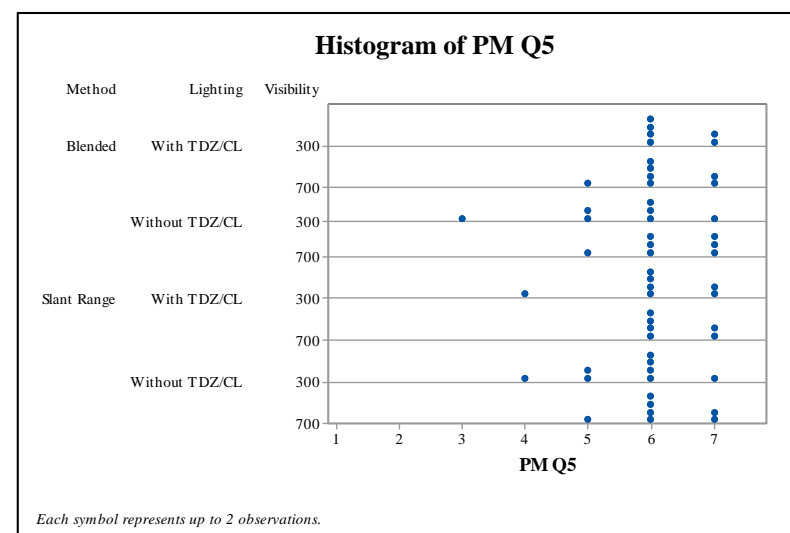
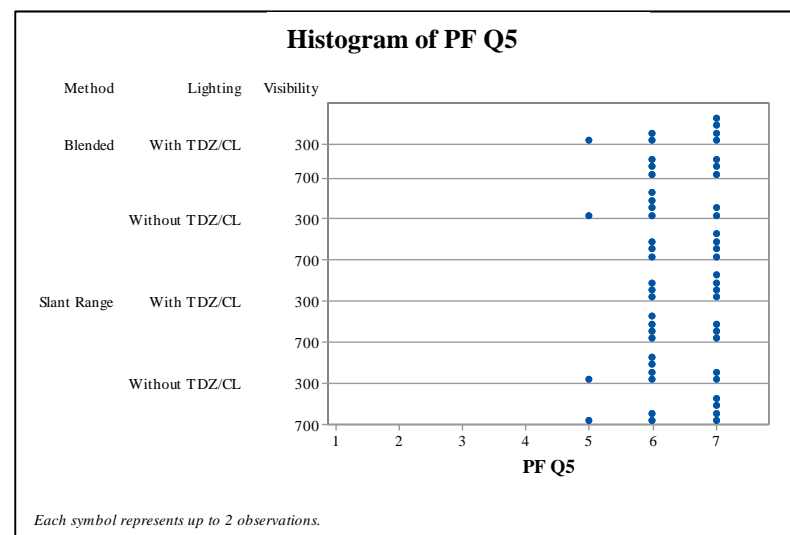
Conclusion: Visibility was significant as a main factor. There was a significant second order interaction between visibility and lighting. Differences are not operationally significant.



Results: Effects of Lighting and Visibility on CVS Method Q5

Descriptive Statistics: PF Q5, PM Q5

Variable	N	Mean	StDev	Minimum	Maximum
PF Q5	96	6.4479	0.5780	5.0000	7.0000
PM Q5	96	6.1146	0.7380	3.0000	7.0000





Effects PM Q5:

- PM Q5: Main Effect for Visibility
 - Significant Difference between 700 RVR and 300 RVR

Tukey Pairwise Comparisons: Response = PM Q5, Term = Visibility

Grouping Information Using the Tukey Method and 95% Confidence

Visibility	N	Mean	Grouping
700	48	6.27083	A
300	48	5.95833	B

Means that do not share a letter are significantly different.

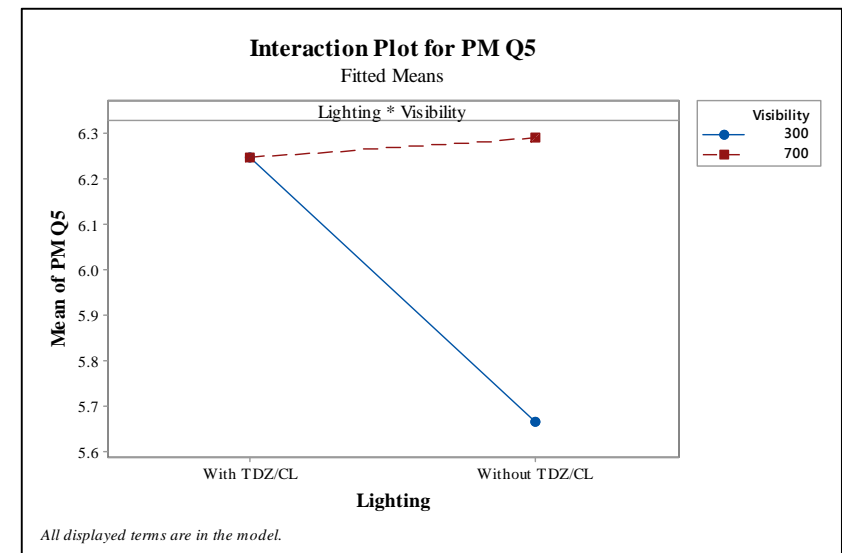
- PM Q5: Secondary Effect for Visibility*Lighting
 - Significant Difference between:
 - 300 without TDZ/CL and 300 with TDZ/CL
 - 700 with TDZ/CL and 300 without TDZ/CL
 - 700 without TDZ/CL and 300 without TDZ/CL

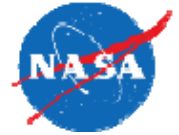
Tukey Pairwise Comparisons: Response = PM Q5, Term = Visibility*Lighting

Grouping Information Using the Tukey Method and 95% Confidence

Visibility*Lighting	N	Mean	Grouping
700 Without TDZ/CL	24	6.29167	A
300 With TDZ/CL	24	6.25000	A
700 With TDZ/CL	24	6.25000	A
300 Without TDZ/CL	24	5.66667	B

Means that do not share a letter are significantly different.





Results: Effects of Lighting and Visibility on CVS Method Q6

General Linear Model: PF Q6 versus Method, Visibility, Lighting

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.0417	0.041667	0.16	0.691
Visibility	1	0.6667	0.666667	2.55	0.114
Lighting	1	0.6667	0.666667	2.55	0.114
Method*Visibility	1	0.0000	0.000000	0.00	1.000
Method*Lighting	1	0.1667	0.166667	0.64	0.427
Visibility*Lighting	1	0.3750	0.375000	1.43	0.234
Method*Visibility*Lighting	1	0.0417	0.041667	0.16	0.691
Error	88	23.0000	0.261364		
Total	95	24.9583			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.511237	7.85%	0.52%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

General Linear Model: PM Q6 versus Method, Visibility, Lighting

Analysis of Variance

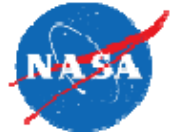
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	1	0.2604	0.26042	0.83	0.366
Visibility	1	0.0937	0.09375	0.30	0.587
Lighting	1	0.2604	0.26042	0.83	0.366
Method*Visibility	1	0.0938	0.09375	0.30	0.587
Method*Lighting	1	0.0104	0.01042	0.03	0.856
Visibility*Lighting	1	0.0104	0.01042	0.03	0.856
Method*Visibility*Lighting	1	0.2604	0.26042	0.83	0.366
Error	88	27.7500	0.31534		
Total	95	28.7396			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.561552	3.44%	0.00%	0.00%

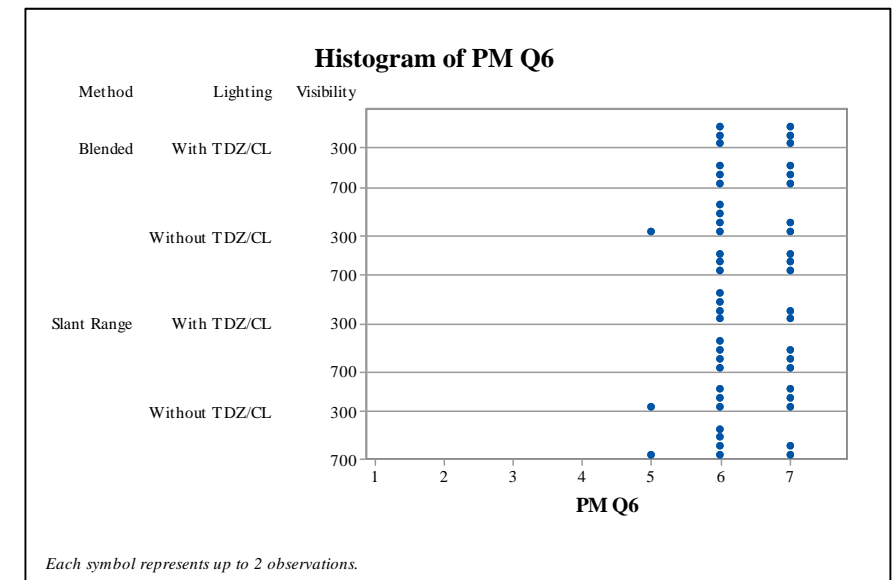
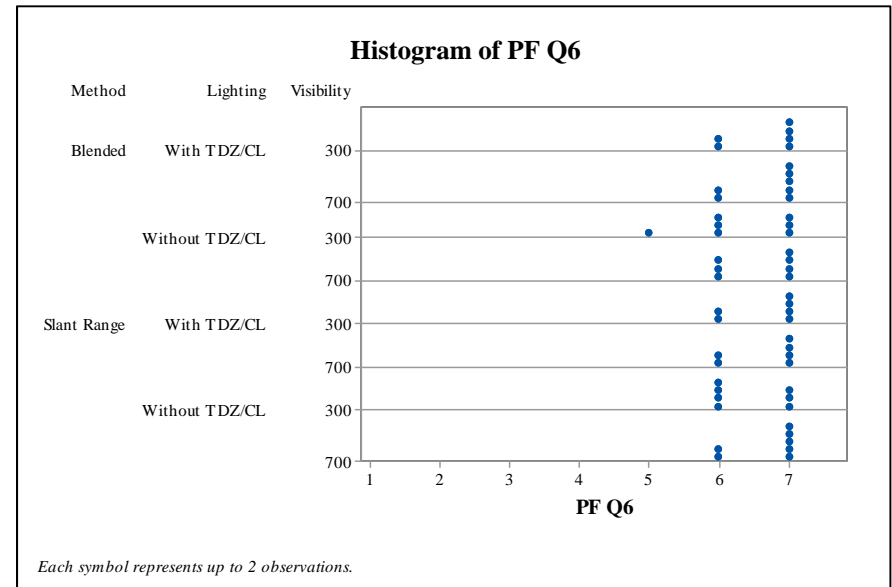
Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

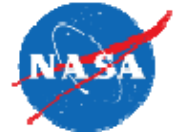
Results: Effects of Lighting and Visibility on CVS Method Q6



Descriptive Statistics: PF Q6, PM Q6

Variable	N	Mean	StDev	Minimum	Maximum
PF Q6	96	6.6042	0.5126	5.0000	7.0000
PM Q6	96	6.3854	0.5500	5.0000	7.0000





Descriptive Statistics

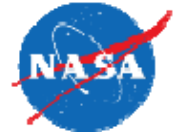
Variable	Method	N	Mean	StDev	Minimum	Maximum							
PF Q1	Blended	48	6.146	0.922	4.000	7.000	PM Q1	Blended	48	5.604	1.086	2.000	7.000
	Slant Range	48	6.021	0.887	4.000	7.000		Slant Range	48	5.604	1.026	2.000	7.000
PF Q2	Blended	48	5.938	1.119	2.000	7.000	PM Q2	Blended	48	5.896	0.751	4.000	7.000
	Slant Range	48	5.938	1.137	3.000	7.000		Slant Range	48	5.771	0.751	4.000	7.000
PF Q3	Blended	48	6.083	0.821	4.000	7.000	PM Q3	Blended	48	5.9792	0.6355	4.0000	7.0000
	Slant Range	48	6.000	0.851	4.000	7.000		Slant Range	48	5.813	0.790	4.000	7.000
PF Q4	Blended	48	6.125	0.789	4.000	7.000	PM Q4	Blended	48	5.813	0.915	3.000	7.000
	Slant Range	48	6.1458	0.6838	5.000	7.000		Slant Range	48	5.833	0.724	3.000	7.000
PF Q5	Blended	48	6.4583	0.5819	5.000	7.000	PM Q5	Blended	48	6.125	0.761	3.000	7.000
	Slant Range	48	6.4375	0.5800	5.000	7.000		Slant Range	48	6.104	0.722	4.000	7.000
PF Q6	Blended	48	6.5833	0.5392	5.000	7.000	PM Q6	Blended	48	6.4375	0.5421	5.0000	7.0000
	Slant Range	48	6.6250	0.4892	6.000	7.000		Slant Range	48	6.3333	0.5586	5.0000	7.0000



Conclusions: Effects of Lighting, Visibility, and Method

- Conclusions:
 - With and without TDZ/CL lighting, 300 and 700 RVR, pilots were able to pick up necessary visual cues to continue approach and landing.
 - PF & PM were able to complete the approach and land safely under all conditions.
 - There was a significant difference in the PF ability to recognize and identify the required visual references under 300 RVR and 700 RVR. Ratings indicate that pilots were still able to recognize and identify the visual references under either visibility. Difference was not operationally significant.
 - There was a significant difference in the PM ability to detect the visual information for sufficient cues to flare and land with and without TDZ/CL lights, although ratings still indicate that the pilot was able to detect the visual cues under either lighting condition. Difference was not operationally significant.
 - There was a significant difference in the PM ability to maintain lateral alignment with the runway under 300 RVR and 700 RVR, although ratings still indicate that the PM was able to maintain lateral alignment. Difference was not operationally significant.
 - PF and PM reported that they were able to complete the approach and land safely given any of the methodologies, under any lighting condition, under any visibility.

ANOVA Results



General Linear Model: PF work versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	1.1167	0.2792	0.36	0.837
Visibility	1	4.8000	4.8000	6.18	0.014
Method*Visibility	4	0.9500	0.2375	0.31	0.874
Error	110	85.5000	0.7773		
Total	119	92.3667			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.881631	7.43%	0.00%	0.00%

Descriptive Statistics: PF work, PM Work

Variable	Visibility	N	Mean	StDev	Minimum	Maximum
PF work	300	60	3.317	0.930	2.000	5.000
	700	60	2.917	0.787	2.000	5.000
PM Work	300	60	2.717	0.825	2.000	5.000
	700	60	2.5167	0.6763	2.0000	4.0000

General Linear Model: PM Work versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	0.2833	0.07083	0.12	0.976
Visibility	1	1.2000	1.20000	1.99	0.161
Method*Visibility	4	0.5500	0.13750	0.23	0.922
Error	110	66.3333	0.60303		
Total	119	68.3667			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.776550	2.97%	0.00%	0.00%

Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q1



General Linear Model: PF Q1 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	2.283	0.5708	0.68	0.604
Visibility	1	1.633	1.6333	1.96	0.164
Method*Visibility	4	2.117	0.5292	0.64	0.639
Error	110	91.667	0.8333		
Total	119	97.700			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.912871	6.18%	0.00%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

General Linear Model: PM Q1 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	9.000	2.2500	1.42	0.232
Visibility	1	1.008	1.0083	0.64	0.426
Method*Visibility	4	2.033	0.5083	0.32	0.863
Error	110	174.083	1.5826		
Total	119	186.125			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.25800	6.47%	0.00%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

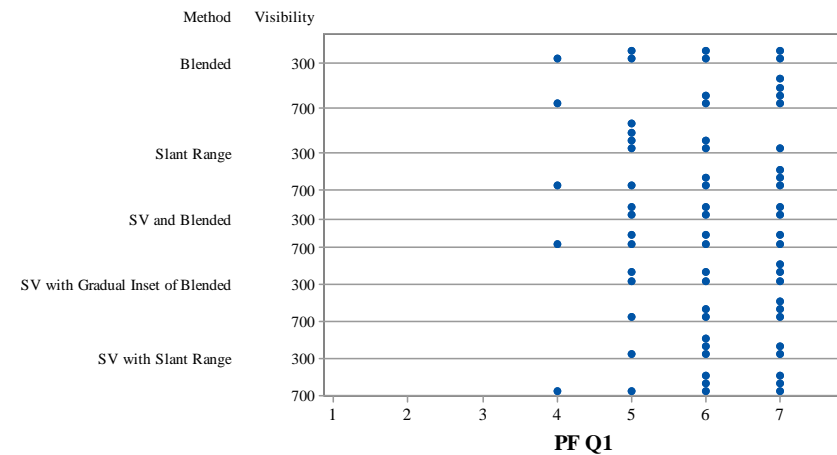
Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q1



Descriptive Statistics: PF Q1, PM Q1

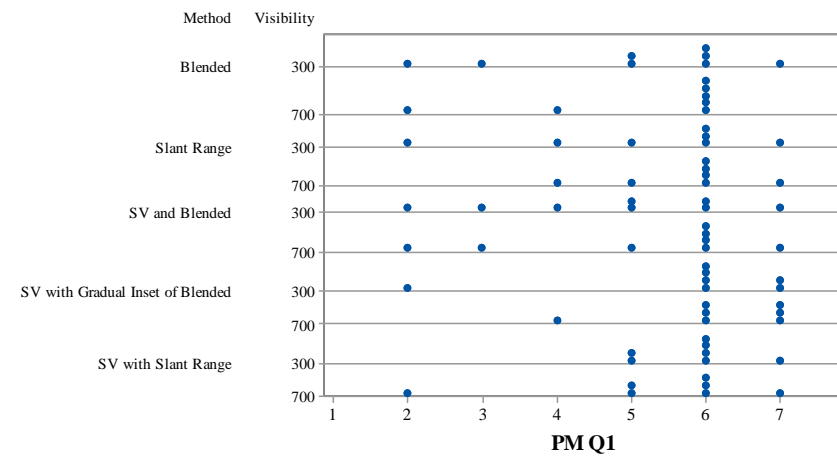
Variable	N	Mean	StDev	Minimum	Maximum
PF Q1	120	6.0500	0.9061	4.0000	7.0000
PM Q1	120	5.625	1.251	2.000	7.000

Histogram of PF Q1



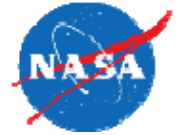
Each symbol represents up to 2 observations.

Histogram of PM Q1



Each symbol represents up to 2 observations.

Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q2



General Linear Model: PF Q2 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	0.117	0.02917	0.02	0.999
Visibility	1	5.633	5.63333	3.78	0.054
Method*Visibility	4	0.617	0.15417	0.10	0.981
Error	110	164.000	1.49091		
Total	119	170.367			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.22103	3.74%	0.00%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

General Linear Model: PM Q2 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	3.550	0.8875	1.47	0.217
Visibility	1	1.008	1.0083	1.67	0.200
Method*Visibility	4	2.450	0.6125	1.01	0.405
Error	110	66.583	0.6053		
Total	119	73.592			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.778012	9.52%	2.12%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

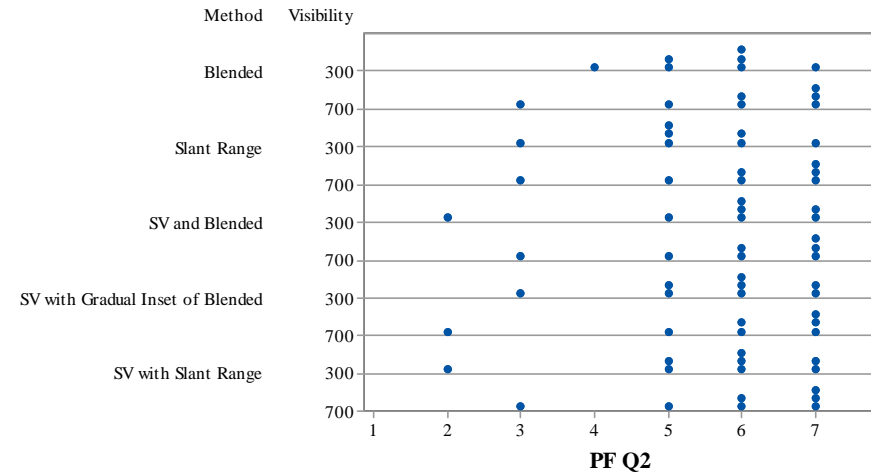
Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q2



Descriptive Statistics: PF Q2, PM Q2

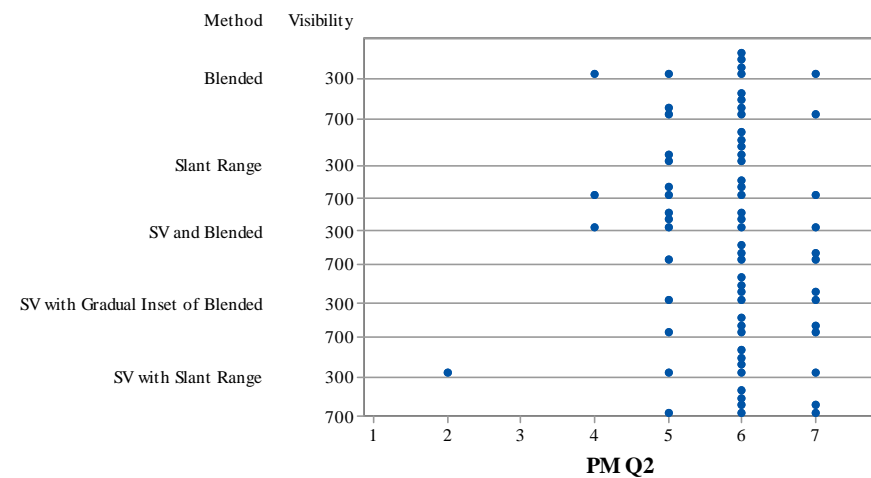
Variable	N	Mean	StDev	Minimum	Maximum
PF Q2	120	5.883	1.197	2.000	7.000
PM Q2	120	5.8917	0.7864	2.0000	7.0000

Histogram of PF Q2



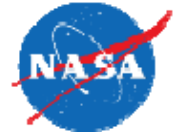
Each symbol represents up to 2 observations.

Histogram of PM Q2



Each symbol represents up to 2 observations.

Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q3



General Linear Model: PF Q3 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	1.117	0.2792	0.40	0.805
Visibility	1	5.633	5.6333	8.15	0.005
Method*Visibility	4	2.950	0.7375	1.07	0.376
Error	110	76.000	0.6909		
Total	119	85.700			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.831209	11.32%	4.06%	0.00%

Conclusion: Significant difference in visibility as a main factor. Difference is not operationally significant.

General Linear Model: PM Q3 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	3.383	0.8458	1.72	0.150
Visibility	1	2.700	2.7000	5.50	0.021
Method*Visibility	4	1.883	0.4708	0.96	0.433
Error	110	54.000	0.4909		
Total	119	61.967			

Model Summary

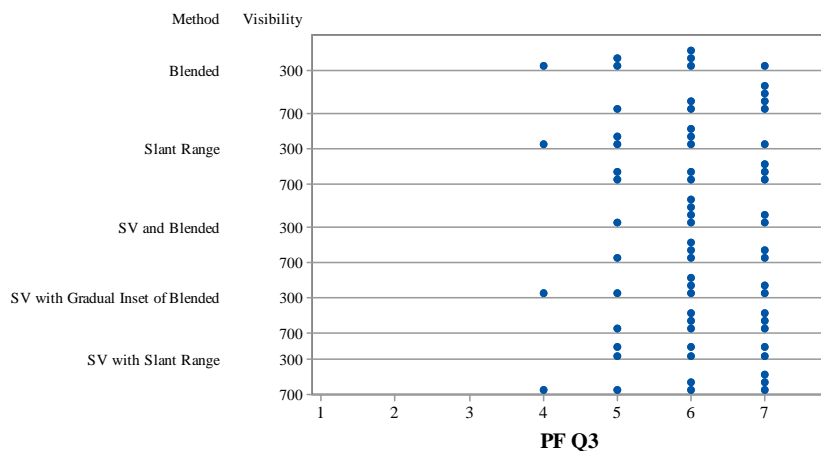
S	R-sq	R-sq(adj)	R-sq(pred)
0.700649	12.86%	5.73%	0.00%

Conclusion: Significant difference in visibility as a main factor. Difference is not operationally significant.

Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q3

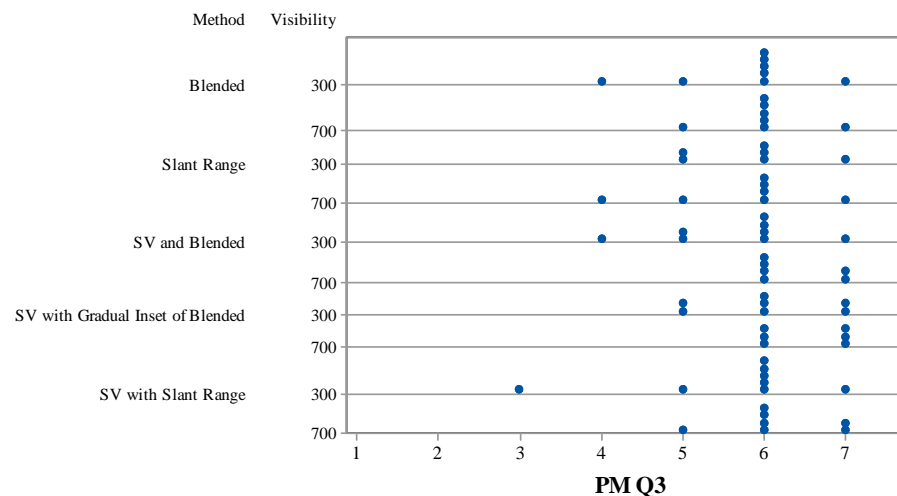


Histogram of PF Q3



Each symbol represents up to 2 observations.

Histogram of PM Q3



Each symbol represents up to 2 observations.



Effects: PF Q3

- Main Effect: Visibility
 - Significant Difference Between 300 RVR and 700 RVR

Tukey Pairwise Comparisons: Response = PF Q3, Term = Visibility

Grouping Information Using the Tukey Method and 95% Confidence

Visibility	N	Mean	Grouping
700	60	6.26667	A
300	60	5.83333	B

Means that do not share a letter are significantly different.



Effects: PM Q3

- Main Effect: Visibility

Tukey Pairwise Comparisons: Response = PM Q3, Term = Visibility

Grouping Information Using the Tukey Method and 95% Confidence

Visibility	N	Mean	Grouping
700	60	6.13333	A
300	60	5.83333	B

Means that do not share a letter are significantly different.

Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q4



General Linear Model: PF Q4 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	2.217	0.5542	0.70	0.594
Visibility	1	15.408	15.4083	19.46	0.000
Method*Visibility	4	1.883	0.4708	0.59	0.667
Error	110	87.083	0.7917		
Total	119	106.592			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.889757	18.30%	11.62%	2.77%

Conclusion: Significant difference in visibility as a main factor. Difference is not operationally significant.

General Linear Model: PM Q4 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	4.217	1.0542	1.26	0.291
Visibility	1	11.408	11.4083	13.60	0.000
Method*Visibility	4	1.050	0.2625	0.31	0.869
Error	110	92.250	0.8386		
Total	119	108.925			

Model Summary

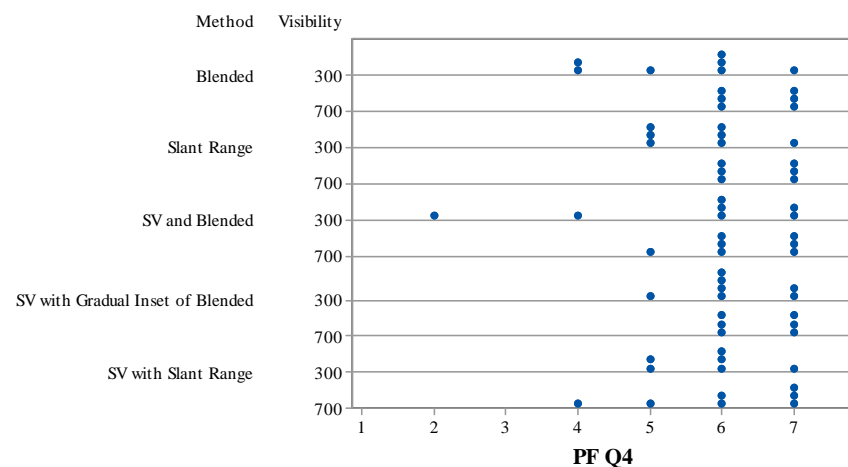
S	R-sq	R-sq(adj)	R-sq(pred)
0.915771	15.31%	8.38%	0.00%

Conclusion: Significant difference in visibility as a main factor. Difference is not operationally significant.

Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q4

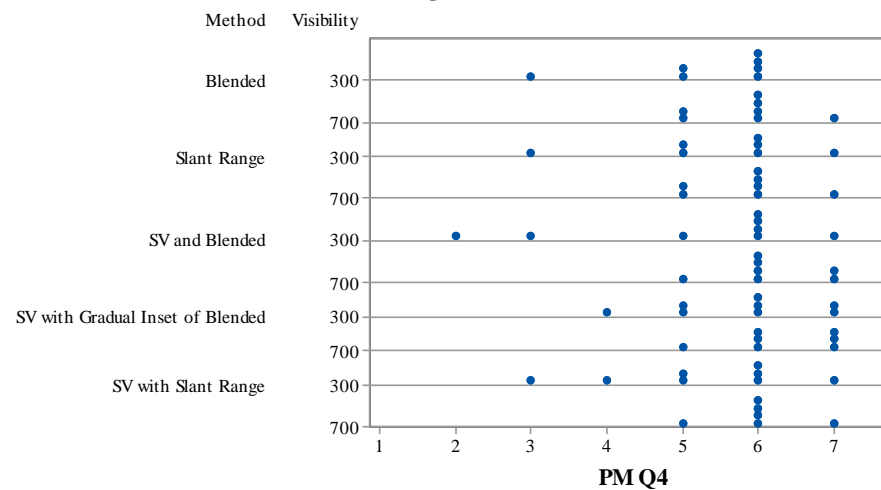


Histogram of PF Q4



Each symbol represents up to 2 observations.

Histogram of PM Q4



Each symbol represents up to 2 observations.



Effects: PF Q4

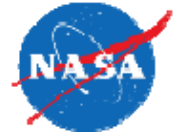
- Main Effect: Visibility

Tukey Pairwise Comparisons: Response = PF Q4, Term = Visibility

Grouping Information Using the Tukey Method and 95% Confidence

Visibility	N	Mean	Grouping
700	60	6.41667	A
300	60	5.70000	B

Means that do not share a letter are significantly different.



Effects: PM Q4

- Main Effect: Visibility

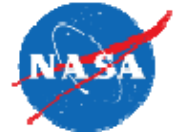
Tukey Pairwise Comparisons: Response = PM Q4, Term = Visibility

Grouping Information Using the Tukey Method and 95% Confidence

Visibility	N	Mean	Grouping
700	60	6.08333	A
300	60	5.46667	B

Means that do not share a letter are significantly different.

Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q5



General Linear Model: PF Q5 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	1.7833	0.4458	0.84	0.505
Visibility	1	0.5333	0.5333	1.00	0.320
Method*Visibility	4	1.3833	0.3458	0.65	0.629
Error	110	58.6667	0.5333		
Total	119	62.3667			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.730297	5.93%	0.00%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

General Linear Model: PM Q5 versus Method, Visibility

Analysis of Variance

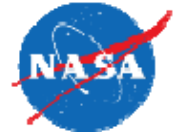
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	1.750	0.4375	0.60	0.661
Visibility	1	12.033	12.0333	16.62	0.000
Method*Visibility	4	1.717	0.4292	0.59	0.669
Error	110	79.667	0.7242		
Total	119	95.167			

Model Summary

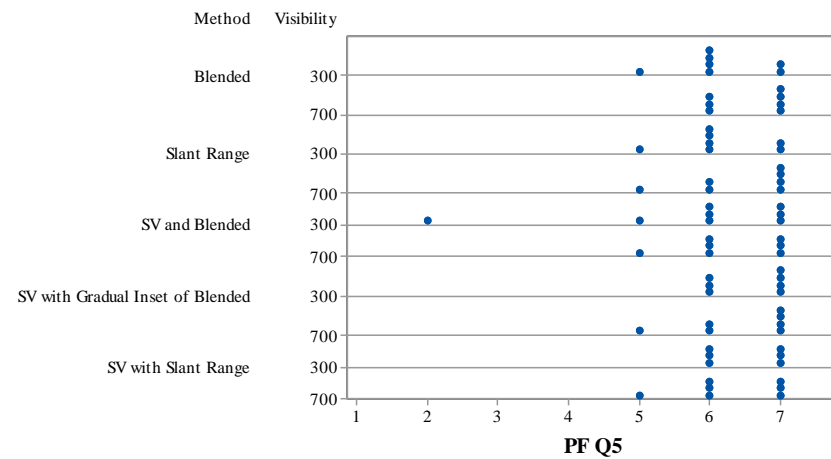
S	R-sq	R-sq(adj)	R-sq(pred)
0.851024	16.29%	9.44%	0.37%

Conclusion: Significant difference in visibility as a main factor.
Difference is not operationally significant.

Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q5



Histogram of PF Q5

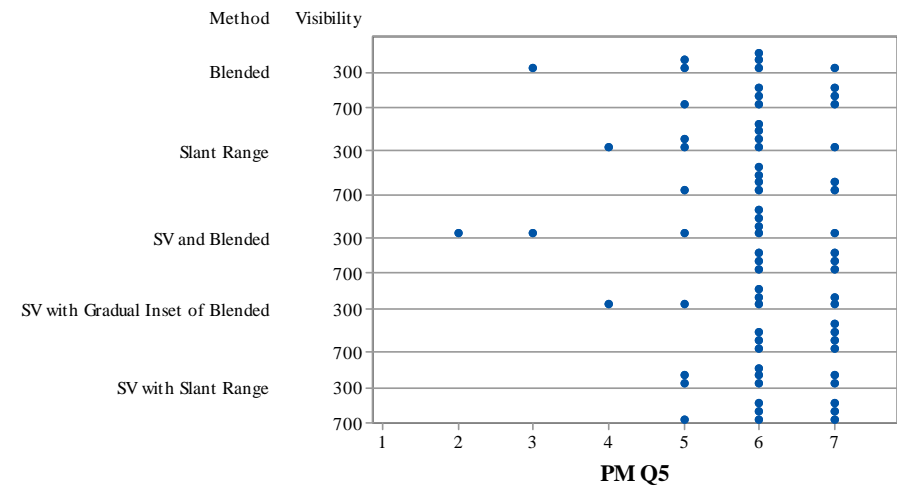


Each symbol represents up to 2 observations.

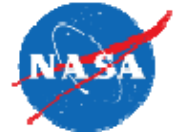
Descriptive Statistics: PF Q5

Variable	N	Mean	StDev	Minimum	Maximum
PF Q5	120	6.3833	0.7239	2.0000	7.0000

Histogram of PM Q5



Each symbol represents up to 2 observations.



Effects: PM Q5

- Main Effect: Visibility

Tukey Pairwise Comparisons: Response = PM Q5, Term = Visibility

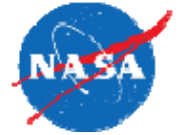
Grouping Information Using the Tukey Method and 95% Confidence

Visibility	N	Mean	Grouping
700	60	6.40000	A
300	60	5.76667	B

Means that do not share a letter are significantly different.

Results: Effects of adding Synthetic Vision to the EFVS HUD

Concept Q6



General Linear Model: PF Q6 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	1.4967	0.3742	0.81	0.518
Visibility	1	1.3569	1.3569	2.95	0.088
Method*Visibility	4	0.6721	0.1680	0.37	0.832
Error	109	50.0530	0.4592		
Total	118	53.4958			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.677645	6.44%	0.00%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

General Linear Model: PM Q6 versus Method, Visibility

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Method	4	0.9176	0.2294	0.63	0.644
Visibility	1	0.7669	0.7669	2.10	0.151
Method*Visibility	4	0.6399	0.1600	0.44	0.781
Error	109	39.8788	0.3659		
Total	118	42.2185			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.604864	5.54%	0.00%	0.00%

Conclusion: No significant difference between main factors, second-order interactions, or third-order interactions.

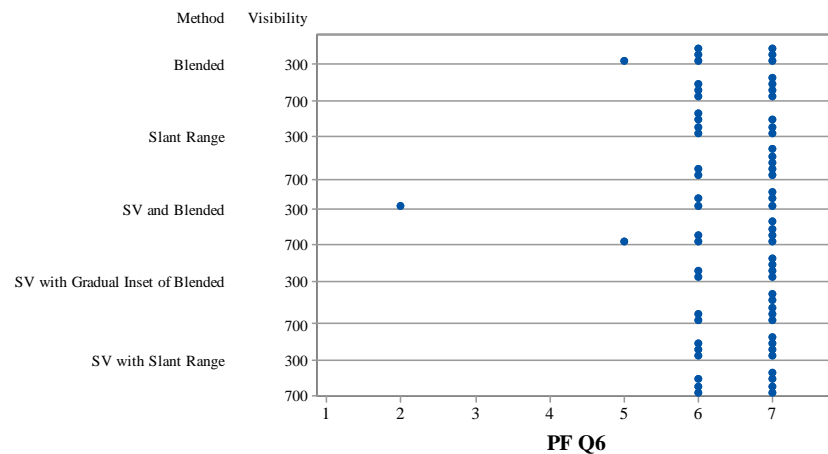
Results: Effects of adding Synthetic Vision to the EFVS HUD Concept Q6



Descriptive Statistics: PF Q6, PM Q6

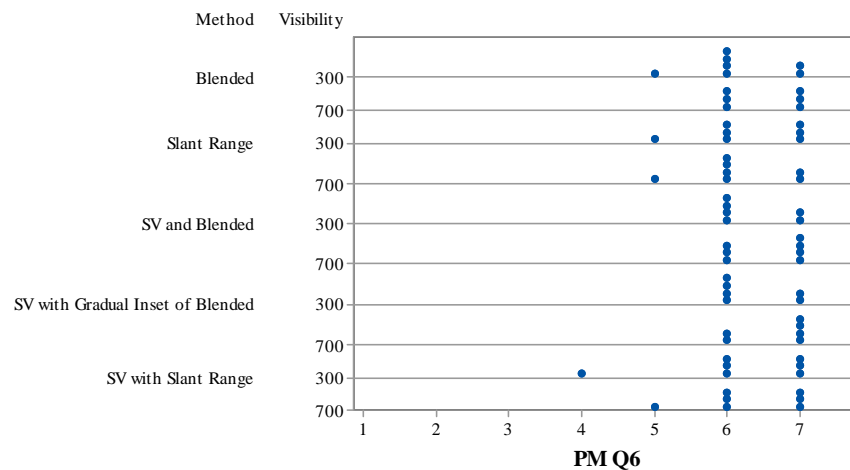
Variable	N	Mean	StDev	Minimum	Maximum
PF Q6	119	6.5462	0.6733	2.0000	7.0000
PM Q6	119	6.3866	0.5982	4.0000	7.0000

Histogram of PF Q6



Each symbol represents up to 2 observations.

Histogram of PM Q6



Each symbol represents up to 2 observations.



Descriptive Statistics PF

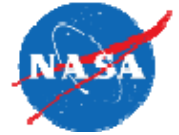
Descriptive Statistics: PF Q1, PF Q2, PF Q3, PF Q4, PF Q5, PF Q6, PM Q1, PM Q2, ...

Variable	Method	N	Mean	StDev	Minimum	Maximum
PF Q1	Blended	24	6.000	1.063	4.000	7.000
	Slant Range	24	5.875	0.947	4.000	7.000
	SV and Blended	24	5.958	0.908	4.000	7.000
	SV with Gradual Inset of	24	6.250	0.794	5.000	7.000
	SV with Slant Range	24	6.167	0.816	4.000	7.000
PF Q2	Blended	24	5.917	1.060	3.000	7.000
	Slant Range	24	5.833	1.167	3.000	7.000
	SV and Blended	24	5.875	1.262	2.000	7.000
	SV with Gradual Inset of	24	5.917	1.283	2.000	7.000
	SV with Slant Range	24	5.875	1.296	2.000	7.000
PF Q3	Blended	24	5.958	0.955	4.000	7.000
	Slant Range	24	5.917	0.881	4.000	7.000
	SV and Blended	24	6.125	0.680	5.000	7.000
	SV with Gradual Inset of	24	6.167	0.816	4.000	7.000
	SV with Slant Range	24	6.083	0.929	4.000	7.000
PF Q4	Blended	24	6.000	0.978	4.000	7.000
	Slant Range	24	6.083	0.717	5.000	7.000
	SV and Blended	24	5.875	1.393	2.000	7.000
	SV with Gradual Inset of	24	6.292	0.624	5.000	7.000
	SV with Slant Range	24	6.042	0.859	4.000	7.000
PF Q5	Blended	24	6.417	0.584	5.000	7.000
	Slant Range	24	6.375	0.647	5.000	7.000
	SV and Blended	24	6.167	1.090	2.000	7.000
	SV with Gradual Inset of	24	6.542	0.588	5.000	7.000
	SV with Slant Range	24	6.417	0.584	5.000	7.000
PF Q6	Blended	24	6.458	0.588	5.000	7.000
	Slant Range	24	6.583	0.504	6.000	7.000
	SV and Blended	23	6.391	1.118	2.000	7.000
	SV with Gradual Inset of	24	6.7083	0.4643	6.0000	7.0000
	SV with Slant Range	24	6.583	0.504	6.000	7.000

Conclusions:

- No significant difference PF & PM workload with or without SV.
- Visibility significant for recognizing and identifying required visual references and detecting visual information for cues for flare and landing. Although there was a significant difference, pilot ratings still indicate that the pilots were able to perform these tasks.

Descriptive Statistics PM



Variable	Method	N	Mean	StDev	Minimum	Maximum
PM Q1	Blended	24	5.375	1.313	2.000	7.000
	Slant Range	24	5.583	1.213	2.000	7.000
	SV and Blended	24	5.333	1.494	2.000	7.000
	SV with Gradual Inset of	24	6.083	1.100	2.000	7.000
	SV with Slant Range	24	5.750	1.032	2.000	7.000
PM Q2	Blended	24	5.792	0.658	4.000	7.000
	Slant Range	24	5.708	0.690	4.000	7.000
	SV and Blended	24	5.833	0.816	4.000	7.000
	SV with Gradual Inset of	24	6.208	0.658	5.000	7.000
	SV with Slant Range	24	5.917	1.018	2.000	7.000
PM Q3	Blended	24	5.917	0.584	4.000	7.000
	Slant Range	24	5.792	0.721	4.000	7.000
	SV and Blended	24	6.000	0.722	4.000	7.000
	SV with Gradual Inset of	24	6.292	0.690	5.000	7.000
	SV with Slant Range	24	5.917	0.830	3.000	7.000
PM Q4	Blended	24	5.583	0.974	3.000	7.000
	Slant Range	24	5.667	0.816	3.000	7.000
	SV and Blended	24	5.792	1.179	2.000	7.000
	SV with Gradual Inset of	24	6.125	0.850	4.000	7.000
	SV with Slant Range	24	5.708	0.908	3.000	7.000
PM Q5	Blended	24	6.000	0.933	3.000	7.000
	Slant Range	24	5.958	0.751	4.000	7.000
	SV and Blended	24	6.000	1.216	2.000	7.000
	SV with Gradual Inset of	24	6.250	0.794	4.000	7.000
	SV with Slant Range	24	6.208	0.721	5.000	7.000
PM Q6	Blended	24	6.375	0.576	5.000	7.000
	Slant Range	24	6.292	0.624	5.000	7.000
	SV and Blended	23	6.478	0.511	6.000	7.000
	SV with Gradual Inset of	24	6.500	0.511	6.000	7.000
	SV with Slant Range	24	6.292	0.751	4.000	7.000